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Biographical Encyclopedia of Astronomers

Springer

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To my teachers

Aldrich Syverson
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Connie Mitchell
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Irwin Shapiro
John Lewis
Reta Beebe
Herbert Beebe
William Eamon
Clyde Tombaugh

Preface

Like that of any human activity, the history of astronomy has been played out under the influence of myriad cultural, institutional, political, sociological, technological, and natural forces. Any history that focuses only on the greatest participants in a field likely misses a great deal of interest and historical value. Inasmuch as astronomy is undertaken by and for human beings, therefore, its history cannot be limited to the lives and achievements of a narrow group.

Here we analyze the lives of people who, in our view, produced some substantial contribution to the field of astronomy, were involved in some important astronomical event, or were in some other manner important to the discipline. In doing so we do not discount the work of countless other journeyman astronomers without whom the science would not have progressed as it has.

Scope

Biographical Encyclopedia of Astronomers [*BEA*] entries presented here do not pretend to illuminate all aspects of a given person's vita. Moreover, some figures included are better known for their enterprises outside of astronomy. In these situations, their astronomical contributions are emphasized.

For many of our entries, the length is limited to something substantially less than 1,000 words due to the lack of available information. There is, of course, an inclination to write a great deal more about persons for whom there is a significant literature already available, *e. g.*, Copernicus, Kepler, Newton, William Herschel, or Einstein. Many such individuals are covered in other standard resources, and we have not felt compelled to repeat all that is already published in those cases. In fact, we look at our entries as a guide to recent scholarship and a brief summary of the important facts about the lives involved. On the other hand, two-thirds of the entries in this encyclopedia are about individuals for whom there is no readily available standard source. In those cases, the length of the article may be longer than might be expected in comparison with those of better known astronomers, and reflects the fact that an entry offers the first (and perhaps only) easily available information about the astronomer involved: It is not difficult to find sources on "Greats" such as Galileo Galilei; however, it *is* hard to find information on Galilei's acolyte, Mario Guiducci.

Citations within the text have been avoided to enhance readability. Nearly all articles end with a list of selected references. The reader is thus presented with opportunities for further research; no article is intended to be a dead end. Toward that end, if we do not provide additional resources for an entry, the subject will be cross-referenced within other articles for which we do provide selected references.

In compiling the selected references, we have tried to include difficult-to-identify secondary sources. At the same time we have largely excluded standard reference works and include only some of the latest canonical works covering the best-known figures in astronomy.

The *BEA* documents individuals born from Antiquity to approximately mid–1918. Subjects may be living or dead. While some ancient figures have become legendary, we have tried to avoid clearly mythological ones. For example, while the royal Chinese astronomers Ho and Hsi (supposedly third millennium BCE) appear in nearly every history of eclipses, they warrant no entry here.

This terminal birth date assures that the subjects written about have completed most of their careers, and that sufficient time likely has elapsed since their featured accomplishments that a historical perspective on their work is possible. Note that almost all of our subjects began their careers before the watershed transformation of astronomy brought about by the events of World War II. It is also true that the number of astronomers significantly increased after this time. Our youngest subject is Gérard de Vaucouleurs; our oldest is Homer.

Inclusion Parameters

Our entry selection embraces a broad definition of the word "astronomer." In modern science, little differentiation is made between the words "astronomy" and "astrophysics"; we do not use such a distinction here. For example, our definition includes astrometrists, cosmologists, and planetologists. These three fields were considered separate and self-contained for most of human history. Cosmology, especially, requires the inclusion of many philosophers and theologians.

Early astronomers often also were astrologers. If they performed astronomical pursuits in addition to simple divination, we include them. Likewise, no distinction is made between the professional and the contributing amateur.

With the exception of a few important cases, instrument makers are included only if they pursued astronomical work with their instruments. Surveyors and cartographers are included if their study of the stars went beyond mere reference for terrestrial mapmaking. Lastly, a select group of authors, editors of astronomical journals, founders of astronomical societies, observatory builders and directors, astronomy historians, and patrons of astronomy are included.

A common pitfall in the history of science is to make the story of a discipline appear to be a single ladder ascending toward modern theory. Instead, it is a tree with many branches, only some of which have led to our current understanding of the Universe. Indeed, seemingly dead branches may become reanimated later in time. And branches may merge as ideas once considered unrelated are brought together. A better metaphor may be a vine, one with many grafts.

Scientists who contributed theories no longer held salient, or who made observations now considered suspect, nonetheless are included on our list if their effort was considered scientifically useful in its time, and the basis for further inquiry. At the same time, scientists whose ideas or techniques are now considered prescient, but who were unrecognized in their lifetimes, may appear as well.

The contributions of persons selected for entries in this work were weighed in the context of their times. Thus, while a contribution made by a medieval scholar might seem small by today's standards, it was significant for its era. We are especially proud of our inclusion of "non-western" figures who often have been given little treatment in histories of astronomy. Finally, we have included numerous entries of fewer than 100 words, some just a sentence or two, to introduce their names and place them in context within the broader vistas of astronomy.

Construction of the subject list was done by the editor-in-chief in consultation with the content editors. Well-known historian of astronomy Owen Gingerich generously volunteered his time to comment upon draft lists. Still, while an earnest attempt was made to make an objective selection of our more than 1,500 entries, responsibility for omissions must rest with the editor-in-chief. Most vulnerable to omission were those born in the last century.

Project Staffing

Author solicitation was done by the editor-in-chief. Many of the shortest entries were crafted by the editor-in-chief; some but not most of these short entries were paraphrased from an unpublished typescript draft titled *Biographical Dictionary of Astronomers*, originally prepared by the historian Hector C. Macpherson in 1940. The standardized format of the articles was arrived at by consensus among the editors. Senior editor Thomas R. Williams's *Author Guidelines* proved indispensable.

Editors were invited to join the project by the editor-in-chief. This editorial board includes, more-or-less equally, individuals who entered history-of-astronomy scholarship with a background either in history of science or in astronomy. (Some have both.) Unlike many encyclopedists, we did not use our editorial role to eradicate the individual writing styles of the authors.

Each content editor was assigned a thematic editorial responsibility, though all were called upon, at one time or another, to edit articles outside of this specialty. The assignments were as follows:

Classical and Medieval Astronomers—Katherine Bracher
Renaissance and Enlightenment Astronomers—Richard A. Jarrell
Nineteenth Century Astronomers—Marvin Bolt
Twentieth Century Astronomers/Astrophysicists—Virginia Trimble
Astronomers of the Islamic World—Jamil Ragep
Nonvocational Astronomers—Thomas R. Williams
Astronomy Popularizers—Jordan D. Marché, II

All content editors also contributed articles to the *BEA*. JoAnn Palmeri edited the vital references for all entries. Additionally she served as our illustrations editor.

For *errata* information, e-mail us at HOCKEY@UNI.EDU

Thomas Hockey
October 2005

Acknowledgments

The *Biographical Encyclopedia of Astronomers* [*BEA*] is above all the product of its authors. These 410 contributors hail from 40 different countries. Nearly every article is an original piece of scholarship. In some cases, scholars about whom entries were written were themselves gracious enough to write articles for us on other subjects.

At the heart of this 6-year project has been its board of editors. Contrary to what the narrow definition of this job title might imply, these people have been actively providing aid, comfort, and advice to the project, since its inception. As to their editorial contribution specifically, this was often far greater, and more time consuming, than is commonly assumed.

The *BEA* was the idea of Peter Binfield (then Business Development at Kluwer). Dr. Binfield's assistant, Ms. Livia Iebba, also provided support "above and beyond." Dr. Harry Blom, Springer's Senior Editor for Astronomy and Astrophysics, traveled many kilometers to meet with the *BEA* editorial board and lend support on the long road to publication.

Usually unsung in a project of this nature are those individuals who did not write for us, but instead recommended other willing and qualified authors. Brevity permits me only two examples: Eva Isaksson of the University of Helsinki and Kevin Krisciunas of the Cerro Tololo Interamerican Observatory.

Brenda G. Corbin at the United States Naval Observatory kindly provided us with a manuscript copy of Hector Copland MacPherson's *Biographical Dictionary of Astronomers* (1940), which was never published. We hope that its use in assembling the *BEA* is similar to what Dr. MacPherson had wished to achieve. Many, though not most, of the shortest entries in the *BEA* were paraphrased from MacPherson's work.

Certain scholars consulted with us on astronomers of specific nationalities. We appreciate the assistance of Alexander A. Gurshtein (astronomers of the former USSR), Suzanne Débarbat (Francophone astronomers), Helge Kragh (Scandinavian astronomers), Robert Van Gent (Dutch), A. Vagiswari (Indian astronomers), Kevin D. Pang (Chinese astronomers), Jochi Shigeru (East Asian astronomers), and Rudi Paul Lindner (Byzantine astronomers).

The bibliographies of recent works in the history of astronomy published by Ruth Freitag (Library of Congress) were enormously useful. So was the Finding List of Obituary Notes of Astronomers (1900–1997) prepared by Hilmar Dürbeck and Beatrix Ott, with contributions by Wolfgang Dick. The Astrophysics Data System of the National Aeronautics and Space Administration was frequently accessed.

The effort of Daniel W. E. Green, Harvard-Smithsonian Center for Astrophysics and International Astronomical Union Center for Astronomical Telegrams, assured that the proper use of new International Astronomical Union comet and minor-planet nomenclatures was maintained.

H. Miller's Thryomanes font facilitated communicating Arabic text between editors. Yuliana Ivakh helped the editor-in-chief with Cyrillic.

Kari Aunan handled thousands of letters during the author-solicitation process. Wesley Even created and maintained the spreadsheet, so necessary for keeping track of the data and long lists generated by the project. Rachel Wiekhorst operated the document scanner. Jeff Guntren prepared the Table of Contents. I am proud to say that all did so while being undergraduate students at the University of Northern Iowa.

Ruby Hockey undertook the cumbersome filing process.

"Thank you" to the members of the Department of Earth Science, University of Northern Iowa [UNI], especially Lois Jerke. I relied on their infrastructure and good humor greatly. Generous, too, was the support of Dean Kichoon Yang, UNI College of Natural Sciences. Linda Berneking of the UNI Donald O. Rod Library, Interlibrary Loan, also deserves special mention.

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Editor Thomas R. Williams would like to acknowledge Peter Hingley, librarian of the Royal Astronomical Society, and Richard McKim, as well as the staff of Fondren Library at Rice University for their assistance.

The editorial board is grateful for the aid received from the many other scholars and librarians, too many to list here, who assisted with facts, citations, and general comments on individual entries. This public support is echoed by officers of the International Astronomical Union Commission 41 (History of Astronomy)/Inter-Union Commission for History of Astronomy, Ileana Chinnici and Wayne Orchiston, who, in the *ICHA Newsletter* #3 (2002), wrote regarding the *Biographical Encyclopedia of Astronomy*: "While the formation of the ICHA came too late for it to be an active participant in the planning phase, we are happy to report that the ICHA Organizing Committee has given the project its whole-hearted support…"

Foreword

In the past four decades, the history of astronomy and cosmology has grown into a professional research area, complete with a journal (*Journal for the History of Astronomy*), sessions devoted to the subject at annual meetings of professional societies, and regular meetings of its own, such as the biennial meetings at the University of Notre Dame. Indeed, the field contains subspecialties, such as archaeoastronomy, that hold regular meetings of their own and have journals.

Astronomy is unique in several respects. First, although the research front in all sciences moves ever faster, constantly increasing the distance between the practitioner and the subject's history, in astronomy the time dimension plays a crucial role in current research (as opposed to, for instance, chemistry), and this means that past data, *e. g.,* of eclipse or sunspot observations, continue to play a role in astronomical research. The historian of astronomy is often the intermediary between the astronomer and these data, especially for earlier periods. Second, among the exact sciences, astronomy is the only field in which amateurs continue to play an active, if supporting, role: In a number of cases professional astronomers rely on the services of the amateurs, and many of the services delivered by these amateurs are very professional indeed. But the lines demarking astronomers from historians and professionals from amateurs are not cut–and-dried. There are museum curators and planetarium educators who are amateurs astronomers or do highly professional research on historical periods, and there are professional astronomers who have an abiding interest in the history of their field for various reasons. And lest we forget, there are very large numbers of readers and television viewers with a passive interest in the history of astronomy for whom the human dimension of the quest to understand the heavens is crucial.

Many of the standard histories of astronomy date from the 1930s and 1950s. But these single-volume histories, which once served both as teaching tools and reference works, have become obsolete in the past few decades. More recent single-volume histories of astronomy can serve only as teaching tools and works of general interest. There has, thus, been a growing need for reference works that cover the results of research into the history of astronomy published in the past half century. Recently, two encyclopedias have been published, *History of Astronomy: an Encyclopedia*, edited by John Lankford, and *Encyclopedia of Cosmology*, edited by Norriss S. Hetherington. Concepts and issues are central in these works. The *Biographical Encyclopedia of Astronomers* is a reference work that focuses on individuals; it adds the human dimension without which no science, or its history, can come to life.

Albert van Helden
Utrecht, September 2005

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If a name within the text appears in **bold**, there exists an entry on that astronomer elsewhere in the encyclopedia.

Introduction

History is the essence of innumerable biographies.
Thomas Carlyle, *Essays*, "On History"

Astronomy has a long and rich tradition, and as the record shows, the history of that tradition is tied closely to collective biography.[1] The present volumes represent a modern attempt to provide a comprehensive biographical encyclopedia of astronomers. The purpose of these volumes is twofold. First, as ready reference, they are designed to provide easy access to biographical information in the history of astronomy. Cutting across space and time, biographical entries are international in scope and cover the period from classical Antiquity to the late 20th century. Second, drawing on a variety of specialized scholars, these volumes aim to serve as an "access point" for continuing research. While individual entries "stand alone" as ready reference, taken collectively, they offer a map of the complex communities that gave science shape.[2] The following introduction has two purposes: first, to sketch the origins of collective biography and its place in the history of astronomy; second, to illustrate the design and use of collective biographies as reference and research tools.

Biography And History

There is properly no history, only biography.
Ralph Waldo Emerson, *Essays*, "History"

History—here I mean historical writing—traces its origins to classical Antiquity, to the celebration of heroes and the lives of great men. Although *lives* were written before Plutarch's aptly titled classic, the modern sense of biography—a fair-minded history of a particular life—took mature form only in the 19th century.[3] The history of writing lives challenges the boundaries that currently separate history, biography, literature, rhetoric, and political commentary. While the roots of modern biography can be traced to the Renaissance (including early examples of science biography), sharp distinctions between "history and biography" are difficult to sustain, not only because the categories continue to overlap but because both share a common ancestor—what we now call collective biography.[4] As background to the present volumes, the following historiographic essay sketches these changing relations.[5]

The origins of *biography* (literally, *life writing*) are found in classical Antiquity as part of a long tradition dedicated to the celebration of heroes.[6] For two millennia, what we now know as *history* was often viewed as philosophy teaching by example. A brief glance at early writers suggests that biography and collective biography share a complex evolution. While Damascius (sixth century) was the first writer to use the Latin term *biographia*, John Dryden was the first to use *biography* in print (1683), this in reference to Plutarch's *Lives.* Words are important but much more was at work. Viewed over time, historical writing included what is now known as history, biography, and collective biography, as well as elements from other branches of the humanities and social sciences.

Biography has served many masters. Between Antiquity and the Renaissance, its main role was to tell the lives of statesmen, philosophers, and saints. As a display of literary and rhetorical skill, its principal aim was to instruct and inspire. Among ancient Greek and Latin authors, the biographical art is evident in the *Lives* of Critias, the *Memorabilia* of Xenophon, the *Lives of the Philosophers* by Diogenes

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[1] I wish to thank the *BEA* Editorial Board for the invitation to write the Introduction. While I have contributed several articles in these volumes, I have had no role in designing or editing the present work.

[2] Collective biography invites the reader to explore the interplay of individuals, ideas, and groups. One scholar went further: "In group biography, one becomes defined by the many. The group biography in fact becomes a protest against the erosion of a viable communal life and marks the socialization of biography as it incorporates several lives, not a single life." Nadel, Ira Bruce (1984) *Biography: Fiction, Fact & Form,* New York, p. 192.

[3] See *Telling Lives: The Biographer's Art,* Marc Pachter, ed., Philadelphia, 1979; *Telling Lives in Science: Essays on Scientific Biography,* Eds. M. Shortland and M. Yeo, Cambridge, 1996; Edmund Gosse, "Biography," in *Encyclopaedia Britannica,* 11th Edition (New York, 1910) Vol. 3: 952–954; Virginia Woolf, "The Art of Biography," *The Atlantic Monthly* 163 (1939): 506–510; and Sidney Lee, "Principles of Biography." *Elizabethan and Other Essays*. Oxford, 1927: 31–57.

[4] Collective biography—short sketches of individual lives representing a group—is a recent term that might be applied to earlier traditions. Collective biography is sometimes associated with prosopography, a method used by social scientists and social historians based on data from collective biography. For an overview, see Helge Kragh, "Prosopography," *An Introduction to the Historiography of Science,* Cambridge, 1987, pp. 174–181. As an example of trends in a specific historical field, see *Fifty Years of Prosopography: The Later Roman Empire, Byzantium and Beyond*, Ed. Averil Cameron, Oxford, 2003.

[5] Historiography—the history of historical writing—suggests that history, biography, and collective biography share common roots. For background, see Herbert Butterfield, "Historiography," *Dictionary of the History of Ideas*, Vols. 2, (New York, 1973): 464–498; for history of science, see John R. R. Christie, "The Development of the Historiography of Science," *Companion to the History of Modern Science*, London and New York, 1990, pp. 5–22, and Helge Kragh, *An Introduction to the Historiography of Science*, Cambridge, 1987.

[6] Over time, biography seized on the individual character of virtue and vice; collective biography celebrated group achievement by virtue of vocation. A counter example is *Catalogus Hereticorum* (1522?) by Bernardus de Lutzenburg, which devotes two chapters to heretics and their errors.

Laertius, Plutarch's *Parallel Lives*, and Suetonius's *Lives of the Twelve Caesars*.[7] It should be noted that these authors are often not identified as historians, but as scholars, poets, or letter writers. When we consider the best-known early historians—from Herodotus (*circa* 480–*circa* 430 BCE) and Thucydides (*circa* 460–400 BCE) to noted writers such as Pliny (23–79), Livy (59 BCE-17), and Vespasiano (1421–1498)—short biography was an essential element in their annals and accounts.[8]

Origins of Modern Biography

The origins of modern biography—the first sustained attempts to write the life of a single individual—can be traced to the Renaissance. The earliest examples were literary. William Roper (1496–1578) wrote the life of Sir Thomas More, George Cavendish (1500–1561?), the life of Cardinal Wolseÿ later, Izaak Walton published a series of biographies, including the life of John Donne (1640).[9] Collective biography also found favor as poets, artists, and scholars joined ranks with statesmen, saints, and kings.[10] Thomas Fuller's *History of the Worthies of England* (1662) extended earlier traditions into more secular territory, while Aubrey's *Minutes of Lives* (its working title) is still widely read today. An early member of the Royal Society, John Aubrey (1626–1697) became interested in biography through his friend, Anthony à Wood (1632–1695), in researching the latter's *Athenae Oxonienses* (1691–1692), a "living and lasting history" of Oxford University based on group biography.[11] The more widely read work is now known as Aubrey's *Brief Lives*.[12] Although Wood judged him "credulous," Aubrey wrote vivid and often intimate biographical sketches, including a number of figures from the New Science—Robert Boyle, René Descartes, Edmond Halley, Thomas Hobbes, Robert Hooke, Nicolas Mercator, and Christopher Wren. Aubrey interviewed many of his subjects. In retrospect, a key problem was the scarcity of personal diaries and journals, as the publication of memoirs and letters was not yet fashionable.[13] Aubrey's contemporary, Thomas Sprat (1635–1713), wrote the *Life of Cowley* (1668) and his better-known *History of the Royal Society* (1667).[14] Drawing on institutional registers and journals, Sprat sprinkled his *History* with short biographies. His aim was to provide living proof of the "usefulness" of "true philosophy." Institutional histories have since used collective biography as a key component in their narratives.

Biography—indeed "science biography"—took recognizable form with the work of Pierre Gassendi (1592–1655). A noted philosopher and astronomer, Gassendi was among the first to write the lives of individual astronomers. An advocate of the New Science, Gassendi employed his knowledge of nature and the language skills of a classical scholar. According to his English translator, Gassendi was "comparable to any of the ancients."[15] His versatility served him well in telling the lives of Nicolaus Copernicus and Tycho Brahe, as well as Georg Peurbach and

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[7] As one example of recent scholarly treatment of ancient biography, see Tomas Hägg and Philip Rousseau, Eds. *Greek Biography and Panegyric in Late Antiquity. The Transformation of the Classical Heritage,* 31. Berkeley, 2000. Examples from other periods include David J. Sturdy, *Science and Social Status: The Members of the Académie des sciences, 1666–1750*. Rochester, New York, 1995 and Frank A. Kafker, *The Encyclopedists as a Group: A Collective Biography of the Authors of the "Encyclopédie."* For an overview of key issues, see Clark A. Elliott, "Models of the American Scientist: A Look at Collective Biography." *Isis*, Vol. 73, No. 1 (March, 1982): 77–93.

[8] From preclassical times, the transition from oral traditions, epics, and story telling (understood as historical literature) was accompanied by the production of records. In addition to annals and chronologies, the earliest forms of government required dynastic lists, while legal considerations of inheritance (as one example of precedence) called for extended genealogies. Between Greek and Roman writers, early forms of historical writing would now be classified as political commentary, contemporary history, or history of the times. Cicero expresses the Roman ideal of the historian as a writer who seeks motives, portrays individual character, analyzes results, and who "supports the cause of virtue and moves the reader by literary artistry." (Herbert Butterfield, "Historiography." *Dictionary of the History of Ideas*, 5. Vols., New York, 1973, Vol. 2: 464–498, p. 470.) Butterfield summarizes the view of Tacitus: "the deeds of good men ought not to be forgotten and that evil men ought to be made to fear the judgment of posterity." "Historiography," p. 479.

[9] He also wrote biographies of Henry Wotton (1651), Richard Hooker (1665), George Herbert (1670), and Robert Saunderson (1678).

[10] A late 16th-century writer lamented: "For lives, I find it strange, when I think of it, that these our times have so little esteemed their own virtues, as that the commemoration and writings of the lives of those who have adorned our age should be no more frequent. For although there be but few sovereign kings or absolute commanders, and not many princes in free states (so many free states being now turned into monarchies), yet are there many worthy personages (even living under kings) that deserve better than dispersed report or dry and barren eulogy." Thomas Blundeville, *The True Order and Method of Writing and Reading Histories,* London, 1574 (no pagination), quoted in *Versions of History from Antiquity to the Enlightenment*, Ed. Donald R. Kelley, New Haven, 1991, 397–413, p. 407.

[11] Wood's *History*, prompted by his friend, Dr John Fell, dean of Christ Church, brought him much fame and notoriety. His grand project, the *Athenae Oxonienses*, was essentially a biographical dictionary mixing historical narrative, collective biography, and bio-bibliography. Assisted by Aubrey and Andrew Allam (neither adequately acknowledged), Wood drew on a variety of printed sources ranging from published works to institutional documents from libraries, archives, and governmental offices. John Fell, influential with the university press, assisted with publication. Wood was eventually sued for libel and removed from the university.

[12] Aubrey's *Lives*, written between 1669–1696, exists in four folio manuscript volumes. The public appearance of the *Lives* has a complicated publishing history. While early editions appeared in the late 18th century, an early standard edition appeared only in 1898. John Aubrey. "*Brief Lives," Chiefly Contemporaries, set down by John Aubrey, between the years 1669 & 1696*. Edited by Andrew Clark. 2 Vols. Oxford, 1898.

[13] Diaries and letters are critical resources for biographers and historians. The best known diaries of this period, published centuries later, include *The Diary of Robert Hooke* (Eds. H.W. Robinson and W. Adams, 1935); *The Diary of Samuel Pepys,* 11 Vols. (Eds. R. Latham and W. Matthews, 1970–1983); and *The Diary of John Evelyn*, 6 Vols. (Ed. E.S. de Beer, 1955–). Publication of personal and scholarly letters began in the 17th century. Early efforts include the letters of N-C Fabri de Peiresc, Galileo Galilei, Johannes Hevelius, and René Descartes, among others.

[14] Thomas Sprat. *The History of the Royal-Society of London, for the Improving of Natural Knowledge*. London, 1667. Sprat's polemic for the New Science is thematic, philosophical, and passionate. His use of biography is not central to his arguments but ever-present in illustrating his claims.

[15] Gassendi's *Vita*, discussed more fully below, was translated by William Rand and published as *The Mirrour of True Nobility & Gentility* (London, 1657).

Johannes Regiomontanus.[16] In retrospect, Gassendi's success was linked to an emerging biographical principle, to portray the "conjunction of life and mind."[17] Like other contemporaries, Gassendi used history to support his scientific claims while shedding light on the inner workings of science.[18] His most cited biography is a tribute to his friend and patron, Nicolas-Claude Fabri de Peiresc (1580–1637). A noted humanist scholar and amateur of science, Peiresc collaborated with Gassendi in astronomy and in conducting optical experiments. Gassendi's biography portrays Peiresc's motives for studying nature and the relation between his personality and worldview. One of the first biographies translated from Latin into English, Gassendi's *Mirrour of True Nobility* (W. Rand, trans., 1657; *Vita* 1641) has been favorably compared to a later classic biography, Boswell's *Life of Johnson* (1791). Gassendi met Boswell's strictest criteria: Boswell's masterpiece is an intimate and telling portrait; it clearly shows that the biographer and subject had "ate, drank, and communed."[19]

Boswell's *Life of Johnson* established biography as a legitimate form of historical writing. Importantly, Boswell's central interest in Johnson's life was to portray the "progress of his mind"—to tell his story accurately but not without passion. For Boswell, in "every picture there must be shade as well as light," and while not wishing "to cut his claws nor make a tiger a cat," his portrait of Johnson included all the "blotches and pimples."[20] Boswell transformed biography into a conventional and fashionable form of historical writing.

By the 19th century, biography gained maturity and great prestige. It was here, in the Century of Science, that a new genre appeared. It is now called "science biography." In the century that followed, particularly after World War II, numerous science biographies appeared. They celebrated traditional heroes as well as obscure figures. Classic studies of Isaac Newton, to take the oldest tradition, illustrate important shifts in the objectives of science biography. Since his death, Newton has been the subject of dozens of studies, from early hagiographic accounts to modern archive-based interpretations devoted to "Newton the Man."[21] Newton posed problems for biographers from the outset, particularly as unknown manuscripts came to light betraying his passion for alchemy, religion, and prophecy. Heralded as the "Splendid Ornament of Our Time" by Sir Edmond Halley, "High Priest of Science" by Sir David Brewster, and "Last of the Magicians" by Baron John Maynard Keynes, Newton's many faces continue to challenge traditional assumptions about the proper relation between science and biography. Despite differences and continuing debate, scholars agree that biography should leave readers less worshipful and more intrigued.[22]

The distinction between biography and history is a modern development. Although both share a common ancestor—and a strong family resemblance—each has a distinct physiognomy. To overstate a difference, biography stems from the belief that history is made by human beings, not by abstract ideas or impersonal forces. Equally overstated, history emphasizes the view that larger themes, trends, and movements account for change. In brief, if biography is a solo instrument, history is an orchestra. The limits of either perspective (assuming such distinctions can be sustained) are clear. In either case, authors assume a point of view. Biographers take the view that life is not encountered

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[16] Latin versions appeared in several editions, the first in Paris (1654), the second in The Hague: Pierre Gassendi, *Tychonis Brahei, equitis Dani, astronomorum coryphaei, vita… Accessit Nicolai Copernici, Georgi Peurbachii, and Ioannis Regiomontani, astronomorum celebrium, vita*. Hagae Comitum (Vlacq) 1655.

[17] See Gassendi's introductory letter to Jean Chapelain in the Preface to Peurbach and Regiomontanus.

[18] Chronology was an important element in the New Science. Practitioners include not only Johannes Kepler and Issac Newton but an extraordinary group that mixed classical studies with advanced skills in astronomy, among them Joseph Scaliger, Wilhelm Schickard, Ismaël Boulliau, J-F Gronovius, John Greaves, Edward Bernard, Nicolas Heinsius, John Bainbridge, Sir Christopher Heydon, J-H Boecler, Henry Savile, James Ussher (archbishop of Armagh), Vincenzo Viviani, and Edmond Halley.

[19] Pierre Gassendi. *The Mirrour of True Nobility & Gentility, Being the Life of the Renowned Nicolaus Claudius Fabricius Lord of Peiresk, Senator of the Parliament at Aix*. Trans. W. Rand, London, 1657.

[20] The phrase "warts and all" biography (perhaps derived from Boswell's "blotches and pimples") resonates with Walt Whitman's charge to his biographer, "… do not prettify me: include all the hells and damns."

[21] The first full-scale biography of Isaac Newton was written by Sir David Brewster (1781–1868), the noted physicist and journalist. Brewster's first excursions in biography were popular. But as author of *The Life of Sir Isaac Newton* (1831) and *Martyrs of Science: Lives of Galileo, Tycho Brahe and Kepler* (1841), Brewster soon found himself defending his principal hero. In 1822, the French astronomer J-B Biot (1822) made claims that Isaac Newton was intellectually crippled by mental illness, and hinted at Newton's questionable moral behavior. A decade later, Francis Baily made much of Newton's unfairness in his *Account of the Rev*^{d} *John Flamsteed* (London, 1835). To defend Newton, Brewster gained access to little-known Newton manuscripts in the Portsmouth Collection (and Hurstbourne Collection). Much to his surprise, Brewster unearthed evidence that linked Newton to unorthodox religious and alchemical views. The result was Brewster's *Memoirs of the Life, Writings and Discoveries of Sir Isaac Newton* 2 Vols. (1855). On balance, Brewster did little to respond to the substance of the claims by Biot and Baily, essentially ignoring Newton's alchemy while denying Newton's illness of 1693. Some 80 years later, L.T. Trenchard More blasted Brewster's approach in his *Isaac Newton: A Biography* (1934). Charging him with playing the role of advocate to "The High Priest of Science," More claimed that Brewster made "almost no attempt to present Newton as a living man or to give a critical analysis of his character" (*Newton*, pp. vi–vii). Into this debate next came the noted economist, John Maynard Keynes (1883–1946). A wealthy collector of rare manuscripts, Keynes acquired hitherto unknown manuscripts of Isaac Newton on alchemy and religion. On the basis of these documents, Keynes famously proclaimed that "Newton was not the first of the age of reason. He was the last of the magicians" ("Newton the Man," 1947, *Newton Tercentenary Celebrations*, 1947, pp. 27–34). A generation later, the noted historian Frank Manuel published an important trilogy, *Isaac Newton, Historian* (1963), *The Religion of Isaac Newton* (1974), and *A Portrait of Isaac Newton* (1968)—a brilliant but controversial psycho-biographical study. Two decades later, a Newtonian synthesis of sorts appeared, *Never at Rest, A Biography of Isaac Newton* (Cambridge, 1980) by Richard S. Westfall. As Newton's biographer, Westfall aimed to "present his science, not as the finished product… but as the developing endeavor of a living man confronting it as problems still to be solved" (p. x). Westfall's credo captures the modern sense of science biography. Subsequent biographers have followed suit. In his *Isaac Newton, Adventurer in Thought* (London, 1992), A.R. Hall suggests the problem with earlier approaches was that the "mythical Newton, a new Adam born on Christmas Day and nourished by an apple from the tree of knowledge, came to obscure the real man who had worked in dynamics, astronomy, and optics" (p. xii). A number of important studies continue to appear. Although the biographical tradition surrounding Newton is longstanding, it shares important similarities with subsequent biographic traditions associated with Charles Sigmund Albert, Darwin, Freud, and Einstein.

[22] Thomas L. Hankins, "In Defence of Biography: The Use of Biography in the History of Science." *History of Science*, 17: 1–16. See also Helge Kragh, "The Biographical Approach," in H. Kragh, *An Introduction to the Historiography of Science,* Cambridge, 1987, 168–173.

as a category or theme. Although it focuses on an individual life, biography can be used as an historical lens to refract the full range of human experience—from individual aspirations to enduring achievements. Those who write "science biography" often aim to show how scientists go about their business, how ideas and theories emerge, and how life and work make a coherent whole. In the end, most readers recognize that biography can be honest without telling the whole truth.

Modern Collective Biography

A biography should either be as long as Boswell's or as short as Aubrey's.
Lytton Strachey

Collective biography—short sketches of individual lives representing a group—traces its roots to classical Antiquity, and since then it has been popularized, institutionalized, and widely embraced.[23] Collective biography has a long tradition of telling the story about science "in the making." Since the time of Aristotle, authors have taken pains to record the efforts of predecessors (if only to show how misguided their views) just as modern authors have summoned ancient authors to support new theories. Applied to astronomy, an important assumption of collective biography is that "astronomy" is not only a body of knowledge but a body of people. It addresses individual lives as well as forms of life. Taken collectively, most astronomers—observers, mathematicians, calculators, astrologers, speculative philosophers—were not heroic figures. While few historians doubt the significance of Newton, many are persuaded of the importance of minor figures.[24] Scholars continue to debate the appropriate balance between individuals and groups.

The history of astronomy—like other scholarly specialities—is inseparably linked to collective biography. Among the early pioneers in this genre, two deserve brief mention: Giovanni Battista Riccioli (1598–1671) and Edward Sherburne (1618–1702). Echoing tradition in his title, Riccioli's *Almagestum novum* (Bologna, 1651) was not the first work to use history as evidence for his cosmological views.[25] Engaged in the great debate over the Ptolemaic, Tychonic, and Copernican world systems, Riccioli used history to tip the scales in favor of an Earth-centered model. A Jesuit by training, Riccioli published his two-volume work in defense of charges leveled against Galileo Galilei (1616 and 1633). Riccioli heaped new observations on old theories to support the Tychonic model.[26] To counter Copernicus's claims, Riccioli marshaled an army of believers in the immobility of the Earth, and not surprisingly, the Copernicans were vastly outnumbered.[27] Working old arguments into a new narrative, Riccioli used history and biography in what amounted to a Copernican counter-reformation. Riccioli's collective biography contains some 400 astronomers from Antiquity to his own age. It fills 20 folio pages—in small type.[28]

Appearing several decades later, Edward Sherburne's *Sphere of Marcus Manilius* (1675) contains the first modern collective biography of astronomers.[29] Responding to wide-spread interest in the ancient astrologer Manilius (flourished 10), Edward Sherburne (1618–1702) presented the first English translation of Book One of the *Astronomicon*, and along with it, his remarkable "Catalogue of the Most Eminent Astronomers, Ancient & Modern." It was a model for future collective biographies. Following earlier traditions,[30] Sherburne's *Astronomical*

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[23] As one recent scholar summarized, "Initially, the analytic life was a minority voice as large, multivolume biographies dominated Victorian lives. However, a tradition originating in short Latin lives, renewed by antiquaries of the 16th century, popularized by Aubrey's *Brief Lives* in the seventeenth, dignified by Johnson's *Lives of the Poets* in the eighteenth, and culminating in works like Strachey's *Portraits in Miniature* in the twentieth, reasserted the centrality of the brief life. In the 19th century, the form reached its apogee in collective lives, biographies in series and biographical dictionaries. Their extraordinary sales and continued influence is a measure of their importance." Ira Bruce Nadel, *Biography: Fiction, Fact & Form,* New York, 1984, p. 13.

[24] One reviewer of the *Dictionary of Scientific Biography* wrote, in some sense "obscure second-rate scientists are as important as, and probably even more significant than, scientific geniuses" given (in his view) that "the real subject matter of the history of science is not the individual scientist, but the scientific community as a whole." Jacques Roger, "The *DSB*: A Review Symposium," *Isis*, 71 (1980): 633–652, p. 650.

[25] Giovanni Battista Riccioli. *Almagestum novum, astronomiam veterem novamque complectens,* (2 Vols.) Bologna, 1651.

[26] The Tychonic model can be described as geocentric and geo-static, and more accurately as geo-heliocentric. A geo-heliocentric model has the planets to revolve around the Sun, but in turn, the Sun revolves annually around the central and stationary Earth. Geo-heliocentric models were in principle observationally equivalent to a heliocentric model. Viewed in context, they served as an intelligent alternative rather than as a "compromise" cosmology. See M.A. Hoskin and Christine Jones. "Problems in Late Renaissance Astronomy." *Le Soleil a la Renaissance*. Paris, 1965. Further details about the history and various mutations of the geo-heliocentric model can be found in Christine Schofield-Jones' doctoral dissertation.

[27] If theory selection is based on *Numerus, Mensura, Pondus*, historians have mused over the number, size, and weight of Riccioli's arguments. By one reckoning, J-B Delambre counted some 57 arguments against a moving Earth. For his part, Riccioli claims "40 new arguments in behalf of Copernicus and 77 against him." See J-B Delambre, *Histoire de l'Astronomie Moderne*, Vol. 1, Paris, 1821, pp. 672–681 and G-B-Riccioli, *Almagest novum*, 2 Vols., (Bologna, 1651). See Volume 2, Section 4, Ch. 1, pp. 290 *et seq.*, where Riccioli expands his list of Copernicans and non-Copernicans weighing arguments for and against a moving Earth; see also pp. 313–351. For Riccioli's reckoning of the number of arguments, see *Apologia pro Argumento Physicomathematico contra Systema Copernicanum adiecto contra illud Novo Argumento ex Reflexo motu Gravium Decidentium*. Venice, 1669; Dorothy Stimson, *The Gradual Acceptance of the Copernican Theory of the Universe*, New York, 1917, pp. 79–84, provides a general discussion.

[28] Riccioli. *Almagestum novum*, Pt I. Following a historical narrative, Riccioli offers a chronological outline of astronomy (xxvi–xxviii) followed by an alphabetical list of over 400 astronomers (xxviii–xlvii). Entry length varies from a few lines to nearly a full page in the case of Tycho Brahe. Though long and often laborious (over 1,500 pages), Riccioli's volumes provide one of the best introductions to the history of astronomy up to his time. Technically skilled and historically inclined, Riccioli provides useful perspectives on contemporary authors, including Copernicus, Brahe, Longomontanus, Kepler, Galilei, Boulliau, and others.

[29] Edward Sherburne, *The Sphere of Marcus Manilius made an English Poem with Annotations and an Astronomical Appendix* (London, 1675).

[30] The more noted early astronomer-historians include Schickard, Gassendi, Riccioli, Boulliau, Viviani, and eventually Halley.

Appendix (pp. 1–126) contains some 1,000 biographical entries, varying from several lines to several pages. Less polemical than Riccioli, Sherburne's purpose was no less passionate. He aimed to tell the story of the "origins and progress" of astronomy from the very beginning—literally, from Adam (5600 BCE). Sherburne's Catalogue contains detailed information about a large number of his friends and colleagues, and it remains useful for historians evaluating contemporary issues and reputations. Young Isaac Newton, as one example, receives a surprisingly short entry—easily dwarfed by those of Tycho and Hevelius.[31]

Collective biography came of age in the 17th century. Although writers continued to celebrate political and religious figures, a shift took place with the appearance of works on artists and scholars as well as advocates of the New Science. During the previous century, Konrad Gesner (1516–1565) published his pioneering *Bibliotheca Universalis* (Zürich, 1545–1549), Giorgio Vasari (1512–1574) his *Lives of the Artists*, and extending a long tradition, the *Acta Sanctorum* (1643 *et seq.*) swelled to 68 folio volumes. This monumental work gave new meaning to the word hagiography.[32] Toward the end of the century, men of learning again took center stage with the appearance of Charles Perrault's *Les hommes illustres*,[33] and soon thereafter, J-P Nicéron's *Mémoires pour servir à l'histoire des hommes dans la République des Lettres* (1729–1745, Paris). Both works included biographies of astronomers.[34]

The most comprehensive work of the century was published by Louis Moréri (1643–1680), *Le Grand Dictionnaire historique* (Lyon, 1671).[35] Unprecedented in scope and rigor, Moréri established new possibilities. For present purposes, while it contained biographies of all the major astronomers up to that day, Moréri's *Dictionnaire* represented unprecedented opportunities for combining history and biography.[36] First published in French, his *Dictionnarie* was soon translated into English, German, Italian, and Spanish, and within a century (1671–1759), some twenty editions appeared.[37] The success of Moréri's work was followed by an avalanche of encyclopedias and dictionaries that constituted an intellectual movement in itself. Less widely noted, the encyclopedia movement was paralleled by the publication of scholarly *Èloges*, most notably by Bernard de Fontenelle (1657–1757) and subsequent secretaries of the French Académie des sciences.[38] Certainly one of the most influential works of the century was the *Dictionnaire historique et critique* (4 Pts, 2 Vols., Rotterdam, 1697) of Pierre Bayle (1647–1706). Later called the "Arsenal of the Enlightenment," Bayle's *Dictionnaire* appeared in five editions over the next 50 years, not including an influential English translation (2nd Edition, 1734–1738).[39] Praised for its topical articles (particularly on reforming religion, philosophy, and politics), Bayle's *Dictionnaire* was less comprehensive than Moréri, and while prone to philosophical polemics, its influence was immense. Like Moréri, Bayle included important biographies on noted thinkers, many associated with the New Science, astronomy, and cosmology. By tradition, Bayle's *Dictionnaire* foreshadowed the *Encyclopédie*, an Enlightenment showcase designed by Denis Diderot (1713–1784), Jean D'Alembert (1717–1783), and other advocates of toleration and reform. The influence of the *Encyclopédie* in transforming political, social, and intellectual institutions would be difficult to overstate. Aided by dramatic increases in literacy, the explosive growth of the printing press, wider use of the vernacular, and the proliferation of learned journals, scholars joined the public sphere as never before, often pointing to Bacon, Galilei, and Descartes as models of free thinking and useful knowledge.[40] Historical evidence and philosophical principle soon became equal partners in political polemics. By the end of the century, collective works multiplied across national boundaries, among the most important, the *Encyclopaedia Britannica* (3 Vols., Edinburgh, 1771) and Chamber's *Cyclopaedia*

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[31] Sherburne, *The Sphere*, Brahe, p. 63; Hevelius, pp, 110–111; Newton, p. 116.

[32] Hagiography can be described as a literary tradition devoted to telling the lives of ecclesiastical figures, notably martyrs and saints canonized by the Church of Rome. Hagiography has since gained a heroic connotation associated with "secular saints" such as Newton, Darwin, Freud, and Einstein.

[33] Charles Perrault. *Les hommes illustres qui ont paru en France pendant ce siècle avec leurs portraits au naturel*, 2 Volumes (1697 and 1700, Paris).

[34] Jean-Pierre Nicéron. *Mémoires pour servir à l'histoire des hommes dans la République des Lettres* (1729–1745, Paris).

[35] Louis Moréri. *Le Grand Dictionnaire historique, ou le mélange curieux de l'histoire sacrée et profane*, (Lyon, 1671 *et seq.*).

[36] The Moréri edition of 1759, for example, contains biographies of astronomers from Antiquity through the early 18th century, among them, Boulliau 2: 137; Copernicus 4: 105–106; Cunitz 4: 324; Descartes 4 (2): 115–119; Galilei 5 (2): 32–33; Kepler 6 (2): 17–18; Mersenne 7: 488; Brahe 10: 181–182; as well as Newton 8: 1001–1002 and other countrymen, Wallis 10: 756; and Ward 10: 764–765. Several articles are particularly noteworthy, for example, the early reception of Descartes's work in universities and subsequent controversies with church authorities is both thorough and unprecedented; the article on J-B Morin contains unique information and is nuanced in interpretation; and Newton is already showing signs of icon status, heralded as one of "the most learned men of our age." The Moréri edition is noteworthy for high standards; articles often quote from primary sources and occasionally from unpublished letters and manuscripts.

[37] Subsequent editions appeared under the editorship of C-P Goujet (1697–1767) and E-F Drouet (1715–1779).

[38] The impulse to publish these éloges (biographies of deceased men of learning) came from several directions. The *éloge* of the French Académie des sciences show similarities with earlier biographical traditions. As idealized portraits "extolling the moral virtues of the post-Renaissance sciences" (p. ix) they represent, as Charles B. Paul has argued, a classic form of collected scientific hagiography. Re-inventing an old tradition, Fontenelle (1657–1757) and his successors (Mairan, Fouchy, and Condorcet) published over 200 posthumous eulogies of Académie members during the 18th century. As commemorative pieces, they underscored societies' debt and popularized the belief that scientists were modest, dedicated, disinterested seekers after truth devoted to social improvement and human progress. See Charles B. Paul, *Science and Immortality: The* Èloges *of the Paris Academy of Sciences (1699–1791).* Berkeley, 1980.

[39] Pierre Bayle. *Dictionnaire historique et critique*, Rotterdam, 1697, fol. 2 Vols. Many editions followed: a second edition (3 Vols., Amsterdam, 1702); the fourth edition (4 Vols., Rotterdam, 1720), edited by Prosper Marchand; and a ninth edition in 10 Volumes appearing shortly thereafter. The second edition of the *Dictionnaire* was translated into English (4 Vols., London, 1709), and later the fifth edition (1730) was translated by Birch and Lockman (5 Vols., London, 1734–1740). Other editions with supplements and additional translations followed, among them a German translation (4 Vols., Leipzig, 1741–1744), with a preface by J.C. Gottsched. It is widely reported that Bayle undertook his *Dictionnaire* due to unacceptable errors and omissions found in Moréri. Later editions of Moréri show a remarkable level of scholarship.

[40] In his *Preliminary Discourse to the Encyclopedia of Diderot* (1751) d'Alembert rehearsed the "traditional litany" of heroes from the scientific revolution (traditionally Copernicus to Newton) explaining how "a few great men … prepared from afar the light which gradually, by imperceptible degrees, would illuminate the world" (Ed. R. Schwab, New York, 1963), p. 74. Voltaire echoed a similar view in his famous chapter on the "Academies" in his *Age of Louis XIV* (*Le Siècle de Louis XIV*, 1751).

(2 Vols., London, 1728).[41] By the end of the century, the publication of private letters of individuals—literary, political, philosophical—became fashionable as learned conversation and salon gossip found its way into print.

The 19th century saw an explosion of multivolume publications. Among them, a new tradition began to emerge with the publication of the complete works of individual scientists—*opera omnia*, collected papers, and published correspondence. Intellectuals increasingly entered the public sphere. One of the early landmarks reflecting the Republic of Letters was the *Biographie universelle ancienne et moderne* (52 Vols. Paris, 1810–1828), edited by J-F Michaud (1767–1839).[42] Spanning time and space, Michaud's *Biographie* remains one of the most enduring universal dictionaries of all time. Boasting high scholarly standards, it is composed of substantial articles signed by eminent authors. As one example, the article on Newton, written by the well-known physicist, Jean-Baptiste Biot (1774–1862), became a symbol of the international and increasingly controversial character of celebrity.[43] As local heroes gained international status, national reputations were hotly disputed. Astronomers were well represented.[44]

An extreme example—finally affecting reputations of both the living and the dead—involved the French mathematician, Michel Chasles (1793–1880), the noted Copley Medalist and Member of the Académie des sciences.[45] In 1867, Chasles claimed that his celebrated countryman, Blaise Pascal (1623–1662), had sent letters (hitherto unknown) to young Isaac Newton during the years 1654–1661. In effect, Chasles suggested that the French mathematician had handed over the secret of the Universe—the law of universal of gravitation—to an Englishman. The dispute that followed involved two years of public wrangling and scholarly exchanges between Newton and Galilei experts—finally followed by a trial and prison sentence. In the end, Chasles came to discover (along with an international audience) that his claims were based on false documents forged by one Vrain-Denis Lucas (1818- *circa* 1871).[46] Chasles eventually acknowledged that he had been duped, swindled, and humiliated.[47] The *Affaire Vrain Lucas* is an extreme example of historical celebrity and national pride gone awry, a dramatic reminder that biography, like other forms of historical writing, is always written from a perspective.

A watershed in collective biography came with specialized dictionaries devoted to individual countries.[48] These "national biographies" have since become showcases of scholarship and—increasingly—for international cooperation. Following a century of political conflict and upheaval, the great national biographies stemmed from a sense of pride and patriotism. First appearing in the early decades of the 19th century, major national biographies began to appear across Europe, from the great universal dictionary of Moréri in France (52 Vols., 1810–1828) to the national dictionaries of Sweden (23 Vols., 1835–1857); the Netherlands (24 Vols., 1852–1879); Austria, 35 Vols., (1856–1891); Belgium (35 Vols., 1866–); Germany (45 Vols., 1875–1900); Great Britain (63 Vols., 1882–1900); the United States (30 Vols., 1928–1936; 1994); France (19 Vols., 1933–); and Italy (59 Vols., 1960–).[49] Although defined geographically, national biographies can be an invaluable resource of information on astronomers, whether major or minor figures.

Among the national biographies that dominated 19th-century scholarly publication, the most eminent was the widely celebrated *Dictionary of National Biography* [*DNB*] (1882–1900). The *DNB* soon became a symbol of scholarly collaboration, not unlike the

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[41] Ephraim Chambers, *Cyclopaedia; or an Universal Dictionary of Art and Sciences, containing an Explication of the Terms and an Account of the Things Signified thereby in the several Arts, Liberal and Mechanical, and the several Sciences, Human and Divine*, London, 1728, fol. 2 Vols. A noted example of publishing letters of the learned is Angelo Fabroni, *Lettre inedite di uomini illustri,* 2 Vols. Florence, 1773 and 1776.

[42] [Joseph-François] Michaud, *Biographie universelle ancienne et moderne,* 52 Vols., Paris, 1810–1828 (32 supplement Volumes); a good deal of the work was completed by his younger brother, Louis-Gabriel Michaud (1773–1858). A second revised edition appeared in 45 Volumes (Paris, 1843–1865).

[43] J-B Biot, "Isaac Newton," *Biographie Universelle*, Vol. 30: 366–404. As noted above, Biot raised important questions about Newton's mental illness—hinting at his beliefs in alchemy and religion—which later spurred a defense by Sir David Brewster as well as a growing tradition of scholarly debate.

[44] Michaud and subsequent editors enlisted the most noted scholars of the day as contributors. Several noted biographies of astronomers were written by J-B Delambre (Kepler; Boulliau; A-G Pingré) and by J-B Biot (Copernicus; Galilei; Newton).

[45] Articles by Chasles, and the many responses, are found in the *Comptes rendus des séances de l'Académie des sciences* beginning in July 1867 (Tome LXV). Consisting of hundreds of pages of text (involving extracts and complete transcriptions of "letters"), the appearance of these exchanges ran from roughly July 1867 to January 1868 (Tome LXVI). By this time, Sir David Brewster joined the fray, along with the English astronomer, Robert Grant. They were joined by scholars from Italy and France, Galileo scholars, among them Pietro Angelo Secchi and Paolo Volpicelli, and French specialists, among them the Pascal scholar, A-P Faugère. The *Affaire Vrain Lucas*, combined with the colossal theft of manuscripts by Guglielmo Libri (1802–1869), may have prompted European archivists to refine the inventories of their manuscript collections. This dramatic display of scholarly effort, fueled by scandal and the loss of national treasures, likely gave impetus to the publication of *Opera* and *Correspondence* of major figures. On the Libri Affair, see P.A. Maccioni Ruju and Marco Mostert, *The Life and Times of Guglielmo Libri (1802–1869), scientist, patriot, scholar, journalist and thief, A 19th century story*. Hilversum, 1995.

[46] On the Vrain-Lucas affair, see Henri Bordier and Èmile Mabille, *Une fabrique de faux autographes, ou recit de l'Affaire Vrain Lucas*. Paris, 1870; *Le parfait secrétaire des grands hommes ou Les lettres de Sapho, Platon, Vercingétorix, Cléopâtre, Marie-Madeleine, Charlemagne, Jeanne d'Arc et autres personnages illustres*, Ed. Georges Girard, Paris, 2003; and Joseph Rosenblum, *Forging of False Autographs, Or, An Account Of The Affair Vrain Lucas*. New Castle, Delaware, 1998.

[47] Although Newton would have been 12 years old at the beginning of the exchange—and despite irregularities in other documents in his possession—Chasles persisted in publishing his views in the prestigious *Comptes rendus* of the Académie des sciences. Overall, Vrain Lucas forged some 27,000 documents, including letters purportedly written by Mary Magdalene, Aristotle, Alexander the Great, and Lazarus (both before and after his resurrection). Virtually all were written in French. Lucas was fond of the scientific revolution; among his favorite figures were Pascal, Galilei, Louis XIV, and Boulliau.

[48] Robert B. Slocum. *Biographical Dictionaries and Related Works; An International Bibliography of More than 16,000 Collected Biographies*, 2nd edition, 2 Vols., (Detroit, 1986) [First edition, 1967]. This volume lists major biographical dictionaries and encyclopedias according to standard categories, from national or area designations to vocation and related thematic distinctions.

[49] See Appendix for further bibliographic details.

Oxford English Dictionary and *Encyclopediae Britannica*.[50] Drawing on hundreds of contributors, the *DNB* contained some 30,000 entries, supplemented by 6,000 additions. The *DNB* was reprinted in 1908, and thereafter, future publication fell to Oxford University Press (1917). Significantly, the *DNB* was viewed not as a completed project but as an ongoing enterprise. That was a century ago. Jumping forward in time, plans were put in place in 1992 to publish the new *Oxford Dictionary of National Biography* [*ODNB*], which was completed in 2004.[51] This modern edition, the most comprehensive biographical dictionary of its kind, contains some 54,922 lives filling 60 volumes. Foreshadowing future efforts in collective biography, the *ODNB* has set new standards by providing electronic online access for subscribers, thus ensuring easy updates and unprecedented capacity for searching and comparing individuals across traditional categories.[52]

Since the Enlightenment

Since the Enlightenment, important developments have taken place in the theory and practice of historical writing. Like other specialized areas of research, the history of astronomy has benefited from increased access to manuscripts and primary sources, not to mention profound changes in educational institutions and dramatic increases in the availability of printed works. These ongoing and often parallel developments began to converge in the form of pioneering works in the history of science. Some of these early works are still available in print, several in the history of astronomy.

A classic example was published by the noted astronomer, J-B Delambre (1749–1822). His impressive multivolume study, *Histoire de l'Astronomie* (1817–1821; 1827) still shows exceptional talent as it moves across ancient, medieval, and modern astronomy.[53] Delambre's work combines the technical skills of an astronomer with the language skills of a classical scholar. Standing the test of time, his six-volume *Histoire* skillfully weaves technical analysis with biographical references—most memorable are entire pages filled with elegant equations. A work for specialists, Delambre's *Histoire* is based squarely on the analysis of published works. Today, his approach might be called "technical thick-description." Although his narrative sails boldly across difficult seas (observation, data reduction, mathematical procedures, and the calculation of tables), his travel-chart is organized around individuals, not concepts or historical periods.

But if Delambre's approach is not thematic, neither is it about *lives*.[54] While his chapter titles and subsections bear the names of individuals, Delambre tells the reader little about his subjects.[55] Instead of a biographical or historical narrative, he offers technical analysis of specific problems. For Delambre and his contemporaries, the use of a "thematic narrative" in the history of astronomy still lay in the future. For now, chronology, bibliography, and technical analysis ruled the day.[56] Delambre's mentor, Joseph-Jérôme de Lalande (1732–1807), echoes the point,[57] and a similar transitional approach is equally evident in the work of a learned contemporary, Alexandre-Guy Pingré

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[50] Known initially by the working title of *Biographia Britannica*, much of the early work was undertaken by the first editor, Sir Leslie Stephen (1824–1901); he was eventually replaced by Sir Sidney Lee (1859–1926). The first volume of the *DNB* appeared on 1 January 1885; the last, number 63, in 1900.

[51] The *ODNB* has been widely reviewed by scholars, and was recently dubbed "the greatest reference work on earth" (*Daily Telegraph*). Stefan Collini, in "Our Island Story," *London Review of Books*, Vol. 27 (20 January, 2005) concludes his review suggesting that "In deeply unpropitious times, the *Oxford Dictionary of National Biography* has refreshed and fortified our sense of what can still be meant by the collective endeavour of 'scholarship.'"

[52] Though widely discussed in recent decades, the advent of electronic texts and powerful search potential continue to change the scholarly landscape. After several minutes searching all the entries in the *ODNB*, I present the following purposely mixed findings: From 50,000 individuals, 3,267 are linked with *science*; within the entire *ODNB*, the word *revolutionary* appears 1,380 times; *child prodigy* 39 times; *intellectually brilliant* 7 times; *arrogant* 307 times; and *quite mad* 3 times. Overall, the *ODNB* contains biographies on 231 astronomers of whom six are women. Searching religious affiliation among the astronomers (selecting from 20 categories) yields two Lutherans (not further specified) and 33 Catholics (not refined here by seven subcategories). Electronic texts allow unprecedented capacities for linking words, concepts, and categories.

[53] Jean-Baptiste Delambre, *Histoire de l'astronomie ancienne*. 2 Vols. (Paris, 1817); *Histoire de l'Astronomie du moyen age*. (Paris, 1819); *Histoire de l'astronomie moderne*. 2 Vols. (Paris, 1821); *Histoire de l'astronomie au XVIII siècle*. (Paris, 1827).

[54] Delambre wrote a number of solid and lengthy biographical articles for the *Biographie universelle*, including articles on Hipparchus, Kepler, La Caille, Lalande, Ptolemy, and Picard. For an overview of Delambre's career, see the works of I. Bernard Cohen cited below.

[55] Delambre's *Histoire de l'Astronomie Moderne,* which lacks a traditional table of contents, contains 16 books; each chapter title except the first (Réformation du Calendrier) is given a single individual name (Copernic, Tycho-Brahé, Képler, etc.) or the names of several individual astronomers ("Métius, Boulliaud, et Seth-Ward"). Minor figures, to Delambre's credit, receive substantial analysis.

[56] A recent scholar suggested that Delambre's "six volume *Histoire* is the greatest full-scale technical history of any branch of science ever written by a single individual" further adding it "sets a standard very few historians of science may ever achieve." (I. Bernard Cohen, "Delambre," *Dictionary of Scientific Biography*. Vol. 4: 14–18, p. 17). Elsewhere Cohen explained that Delambre's approach was to go through "each chronological period by describing and analyzing first one treatise and then another [he] thereby avoids any attempt at a historical 'synthesis,' or generalization, largely confining himself to critical analyses and expositions of major and minor contributions within the rigid framework . . . ." "Introduction," J-B-J Delambre, *Historie de l'Astronomie Modern*, Reprint, New York, 1969, p. xvi.

[57] Jérôme de Lalande (1732–1807) published a similarly impressive work—again, still useful today—that followed the tradition of linking units of information along a clean chronological line. It would now be known as annotated bibliography, *Bibliographie astronomique avec l'histoire de l'astronomie depuis 1781 jusqu'à 1802*. (Paris, 1803). Not a history but a reference tool, Lalande's *Bibliographie* lists every known astronomical work from *circa* 480 BCE to 1802. Containing some 660 pages, it was unrivaled as a chronological bibliography of the history of astronomy. By design, it also served as a chronological list of astronomers. At the end of his book, Lalande provided a concise "history of astronomy" (1781–1802), in effect, a calendar of astronomical events and activities similar to the annual publications of the *Académie des sciences*. A similar model was adopted by G. Bigourdan in publishing the work of A-G Pingré (see below).

(1711–1796).[58] But organizational approaches to historical writing were changing. At the close of the century, Adam Smith (1723–1790), the noted economist, developed a more thematic approach in his *Principles Which Lead and Direct Philosophical Enquiries; Illustrated by the History of Astronomy* (1795).[59] As the title suggests, Smith used history to explore the roots of human progress. As an ancient form of knowledge, astronomy provided Smith with an example that linked material and moral improvement.[60] Many of these early historical writings mixed technical analysis with bio-bibliography. In varying degrees, each shows a shift toward narrative, from chronicling events to evaluating themes. An important virtue of historical narrative is that it accommodates "time's arrow" along with traditional interests in analysis, biography, and bibliography.[61]

Since the Enlightenment, research and reference tools have appeared in growing numbers, and as philosophy and science have became more specialized, historical works have followed suit. In the history of science, the German physicist and bibliographer, Johann Christian Poggendorff (1796–1877) published a pioneering biographical handbook. Poggendorff's evolving multivolume *Biographisch-Literarisches Handwörterbuch der exakten Naturwissenschaften* (1863–1904, *et seq.*) initially contained some 8,400 biographical entries. It was the first comprehensive bio-bibliographical work of its kind. Although it emphasized the physical and exact sciences, it covered all countries and chronological periods.[62] Outside the physical sciences, William Munk (1816–1898) published his *Roll of the Royal College of Physicians* (3 Vols., 1878), one of many multivolume works showing increased specialization. An example: George Sarton (1884–1956), among the early founders of the discipline, provided a detailed roadmap to ancient science in his *Introduction to the History of Science* (1927–1948, Baltimore).[63] Continuing the journey (ancient to medieval) Pierre Duhem (1861–1916) published his monumental *Le système du monde*, 10 Vols. (1913–1959, Paris), providing a detailed study of the physical sciences, including the history of astronomy.[64] Similarly styled encyclopedic narratives appeared by Lynn Thorndike (1882–1965), *History of Magic and Experimental Science* (8 Vols., 1923–1958),[65] while R.T. Gunther's *Early Science in Oxford* (14 Vols. 1923–1945, Oxford) is more typical of institutional works. As pioneers, Sarton, Duhem, Thorndike, and Gunther represent a transitional encyclopedic tradition that joined bio-bibliography with a thin chronological narrative. Finally, a more recent trend in collective biography is evident in "Who's Who" publications. These works have helped fill biographical gaps left by other approaches, particularly in the professions. One of the most comprehensive works of collective science biography contains some 30,000 entries, *The World Who's Who in Science: A Biographical Dictionary of Notable Scientists, From Antiquity to the Present* (Chicago, 1968), edited by Alan Debus.[66]

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[58] Pingré's *Annales céleste du dix-septième siècle* (1901), as the title suggests, is based on a year-by-year celestial calendar; it offers a treasure trove of detailed information about celestial events, observations, publications, and people. Like his predecessors, Pingré's skeletal structure was never fleshed out; there is no narrative theme and little life, although it sometimes offers exceptional biographical insight.

[59] Two early historians of astronomy, James Ferguson (1710–1776) and Robert Grant (1814–1892), followed similar strategies of mixing biography and historical narrative that echoed the interpretive themes of their day (Robert Grant, *History of Physical Astronomy, From the Earliest Ages to the Middle of the Nineteenth Century* (London, 1852)). Grant's title may be misleading. His 14-page introduction covers the period up to Newton; the following 13 chapters are devoted to the theory of gravitation, particularly the genesis and reception of the "immortal discoveries of Newton" (p. 20). Although occasional flourishes of whiggism may jar the modern reader, Grant's *History* remains impressive. On the solid basis of primary sources, it shows admirable technical mastery, historical rigor, and remarkable rectitude of judgment.

[60] Striking a more traditional note, Joseph Priestley (1733–1804), a Unitarian minister, echoed a similar theme. Priestly saw the natural philosopher as "something greater and better than another man" as his work involved the "contemplation of the works of God." Joseph Priestley, *The History and Present State of Electricity, with Original Experiments*. 2 Vols., 3rd ed. (London 1775): Vol. 1, p. xxiii.

[61] Earlier historians with interests in other areas had been emphasizing topical and thematic approaches since the beginning of the 17th century, notably John Selden (1584–1654) and the noted French historian, Jacques Auguste de Thou (1553–1617). In the nascent history of science, more thematic approaches are evident in William Whewell, *History of the Inductive Sciences* (1837). Voltaire, their contemporary, is widely noted for stretching historical narratives from political concerns to science, learning, and the arts. Although a trend toward historical narrative is evident in the history of science, two later classics, by Arthur Berry (1898) and J.L.E. Dreyer (1906), continued to entitle chapter headings (and many subsections) with the names of specific individuals. Biography remains an important organizational strategy in the history of astronomy.

[62] Johann Christian Poggendorff (1796–1877), Professor at the University of Berlin (1834), served as editor of *Annalen der Physik und Chemie* (1824–1877) and was a member of the Prussian Academy of Sciences (1839). Poggendorff's work first appeared in two volumes (1863) and gradually expanded into seven parts ("Band I" to "Band VII," 1863–1992; Part 8 was begun in 1999). Poggendorff is particularly strong for the physical sciences—astronomers, mathematicians, physicists, chemists, mineralogists, geologists, naturalists, and physicians. An electronic version of Poggendorff's work is now available in database format. It reportedly contains entries for some 29,000 scientists from ancient to modern times. The electronic edition (DVD) is under the auspices of Sächsische Akademie der Wissenschaften zu Leipzig. See Appendix for bibliographic details.

[63] George Sarton. *Introduction to the History of Science*. 3 Vols., Baltimore: Williams and Wilkins, 1927–1948.

[64] Pierre Duhem. *Le système du monde, Histoire des doctrines cosmologiques de Platon à Copernic*. The volumes include *I. La cosmologie hellénique; II. La cosmologie hellénique; III. L'astronomie latine au Môyen Age; IV. L'astronomie latine au Moyen Age; V. La crise de l'aristotélisme; VI. Le refus de l'aristotélisme; VII. La physique parisienne au XIV^e siècle; VIII. La physique parisienne au XIV^e siècle; IX. La physique parisienne au XIV^e siècle; IX. La cosmologie de XV^e siècle. Ecoles et universités.*

[65] Lynn Thorndike. *A History of Magic and Experimental Science* (8 Vols., New York, 1923–1958).

[66] Several thematic reference works have appeared in recent decades, notably the *Dictionary of the History of Ideas* (1974), now in a new edition; *Encyclopedia of Philosophy* (1967); *Companion to the History of Science* (1990); and particularly useful for identifying minor figures, the *Isis Cumulative Bibliography* (1971–).

An important scholarly tradition—which continues today—emerged in the 19th century with the publication of the complete works of noted scholars and scientists.[67] No discussion of science biography would be complete without mentioning the significance of these scholarly monuments. Among the oldest and most powerful research tools for historians of science, these works first appeared as *opera omnia, oeuvres complètes*, or as *Lettres* or *Complete Correspondence* of the traditional heroes of our discipline. Contemporary interest in heroic individuals reflects the philosophy of science at the time, not to mention nationalistic tendencies and expressions of local pride.[68] Challenging in scope and complexity, the extant body of letters and manuscripts of leading scientists required exceptional scholarship, collective effort, and substantial institutional support. Arguably, these requirements help define modern collective biography as well as the character of private, institutional, and national funding. Because these works have appeared over the course of several centuries, it is instructive to consider changing standards of scholarship.[69]

Heralded as "one of the most ambitious projects ever undertaken in studies of the history of science," the *Dictionary of Scientific Biography* (*DSB*) (1970–1980) occupies an important place at the end of this brief historical introduction.[70] The *DSB*, sponsored by the American Council of Learned Societies and supported by the National Science Foundation, has been identified as a collaborative work that at once asserted and affirmed the identity of a discipline.[71] Published with remarkable speed and regularity in the course of a decade (1970–1980), the original 16-volume set includes over 5,000 biographical entries in the history of science from Antiquity to the 20th century.[72] Overall, the scholarly response to the *DSB* was extremely positive. Some proclaimed it "magnificent" and "triumphantly executed," others offered detailed criticism and useful suggestions.[73] In the end, despite the unprecedented scope of a project this size, most reviewers returned to time-honored principles that define the design and use of collective biography—*inclusion criteria*, *entry length*, and issues of *coverage*. By tradition, key areas of concern turn on the relative importance of historical figures—their positive contributions, contemporary influence, subsequent significance, and their role in representing or typifying a group. Difficult decisions are involved. To suggest the size of the problem, what weight does a Leviathan like Isaac Newton have compared to a small fry like John Newton (a contemporary almanac writer)? Scholarly reviews of the *DSB* reconfirm a diversity of opinion—and sustained acceptance—of collective biography.[74] Classified by field, the *DSB* contains articles on some 750 astronomers, most from the modern period.[75]

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[67] A selected list, considered chronologically, includes Pierre Gassendi, *Opera Omnia* (6 Vols., Lyon, 1658); Benedict de Spinoza, *Opera Posthuma* (Amsterdam 1677), Dutch edition, *Die nagelate Schriften van B. d. S.* (n.p., 1677); J. Bernoulli (1744); René Descartes (1824–1826 *et seq.*); Johannes Kepler (*Opera*, 1858–1871; *GW*, 1935–); A- L. Lavoisier (6 Vols., 1862–1893); C. F. Gauss (12 Vols., 1863–1933); J- L. Lagrange (14 Vols., 1867–1892); P-S Laplace (14 Vols., 1878–1912); A- L. Cauchy (26 Vols., 1882–1970); Christiaan Huygens (22 Vols., 1888–1950); René Descartes (12 Vols., 1897–1913); Galileo Galilei (20 Vols., 1890–1910); Blaise Pascal (14 Vols., 1904–1914; 1964–1992, *et seq.*); Leonard Euler (43; 72 Vols., 1909; 1911–1996); Tycho Brahe (15 Vols., 1913–1929); G-W Leibniz (1923–); Isaac Newton (7 Vols., 1959–1977); Nicolaus Copernicus (4 Vols., 1978–); Robert Boyle (1999–2000; 2001); and Albert Einstein (1987–). Similar volumes have recently appeared for Thomas Hobbes (1994), John Flamsteed (1995–2003), and John Wallis (2003 et seq.). Taken separately, less heroic figures have attracted scholarly interest, savants such as N-C Fabri de Peiresc (1888–1898; 1972), Marin Mersenne (1932–1986), and Henry Oldenburg (1965–1986). The *Discepoli di Galilei* (1975–1984) was designed to shed light not only on individuals but working groups. See Appendix for bibliographic details.

[68] On the title pages of one edition of Galilei's works, for example, one finds in over-sized colored type the name of Benito Mussolini. In France, Philippe Tamizey de Larroque, editor of the *Lettres* of N-C Fabri de Peiresc, was a enthusiastic but unrepentant promoter of his hero, the glory of Provence.

[69] As an example, Johannes Kepler has two major editions dedicated to his work. Christian Frisch edited the first major edition, *Joannis Kepleri opera omnia* 8 Vols. (Frankfort and Erlangen, 1858–1871); the more recent appeared as *Gesammelte Werke* (22 Vols., Munich, 1938–). The differences are notable. As an example, Frisch presents Kepler's letters unsystematically, sometimes appended to various parts of his relevant published works. The modern *Gesammelte Werke*, by contrast, supplies the complete text of all known correspondence organized and annotated in familiar modern format. A second example involves the *Lettres* of N-C Fabri de Peiresc. In more than one instance, the editor of Peiresc's letters, Tamizey de Larroque, combined various versions of letters (originals, drafts, copies) in a well-meaning effort to provide a more complete text—but alas, without alerting the reader. Larroque sometimes omitted portions of Peiresc's published letters (and on occasion entire letters) judging them "too scientific."

[70] Another reviewer proclaimed the *DSB* the "greatest contribution to scholarship in the history of science of the second half of the 20th century."

[71] The *DSB* was "designed to make available reliable information on the history of science through the medium of articles on the professional lives of scientists. All periods of science from classical Antiquity to modern times are represented, with the exception that there are no articles on the careers of living persons." (Preface). *DSB* entries are signed and usually include a bibliography; geographical coverage is international, although China, India, and the Far East are not treated as extensively as others.

[72] The *DSB* appeared in 16 Volumes during the years 1970–1980, followed by supplements. Entries provide the subject's birthplace and date, family information and background, education and intellectual development, treatment of growth and directions of the subject's scientific work and scientific personality in relation to predecessors, contemporaries, and successors. Inclusive across time and space, entry length was in three categories (300–700; 700–1300; and 1300–3600 words), reflecting the individual's contribution and influence.

[73] A brief survey suggests three principal concerns: thematic boundaries defining the group; inclusion criteria; and relative length of entries. As general principles, collective biography should be inclusive, symmetrical, authoritative, and where possible, based on primary sources. In practice, editors wisely supply contributors with an editorial "boiler plate" to ensure symmetry (date and place of birth and death; parents and siblings; birth order position; religion; education; publications; friends; students; appointments and honors; institutional affiliations; contemporary influence; personal finance; work habits; motives for pursuing science; etc.). One reviewer of the *DSB* suggested editors request "guideposts" to cue readers: "the subject's most significant work is X," or "a critical influence was Y." Editorial decisions are particularly acute when major collective biographies (such as the *DNB* and *DSB*) are reduced to a single comprehensive volume. The *Concise Dictionary of National Biography* (Pt. 1, Oxford, 1903; 2nd Ed. 1906) consists of entries one-fourteenth the number of words from the parent edition. Entries in the *Concise Dictionary of Scientific Biography* (New York, 1981) are 10 percent the length of those in parent volumes.

[74] The *DSB* is currently being revised and expanded to include individuals from the 20th century and those previously omitted. The new *DSB* will be in electronic format and fully searchable.

[75] The *Concise* DSB contains "Lists of Scientists By Field" (749–773) which facilitates this rough estimate; arguably, a more accurate reckoning would be 500 "astronomers."

Conclusion

Readers of the *BEA* will find a familiar format aimed at easy access. The only notable departure from tradition is that individual entry length shows less dramatic variation than in earlier works. With an eye toward supplying specialists and laymen with appropriate references, individual entries vary from 100 to 1500 words. Readers may note that entries for the likes of Newton and Einstein may be rivaled by less-known astronomers. The rationale is twofold: First, entry length helps rescue a number of astronomers from relative oblivion; second, it provides readers with scarce information not readily found in secondary works, sometimes not available in English or in modern languages. Major figures continue to receive substantial entries but with less lengthy largesse. This strategy also reflects the wider availability of source material for major figures.

As we look to the past, collective biography has not only proven adaptable to changes in historical writing, it has been central to the story from the start. Like other forms of scholarship, individual works of collective biography will continue to be judged by their rigor, utility, and scholarly merit. But while readers have come to expect increasingly higher levels of expertise, inclusion, and ease of access, most modern readers remain curiously consistent—even old fashioned—in their expectations about biography. As in the past, readers will continue to appreciate an appropriate anecdote, particularly if it puts a face on a thought or makes a life and career more coherent. In the end, the lives of scientists are human lives, and if *biography* is about an individual life, *collective biography* is about *forms of life*. Biography, like astronomy, has a long and rich tradition. It tells the story of forgotten constellations; it contemplates patterns of human acheivement and human aspiration. Those now distant worlds—puny and brief—seem no less majestic, no less alluring.

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Appendix

Reference and Research Resources

This list of biographical sources is suggestive, not exhaustive. It aims to provide selected sources that may be useful for identifying biographical sources in the history of astronomy and cosmology. Additional detailed research can be pursued by means of specialized scholarly studies found in the second section, which includes the complete works, correspondence, and cumulative bibliographies of noted figures. For further information on biographical reference sources, see Robert B. Slocum. *Biographical Dictionaries and Related Works: An International Bibliography of Approximately 16,000 Collective Biographies*, 2 Vols., 2nd ed., Detroit, 1986.

Selected Reference Sources

ADB (*Allgemeine Deutsche Biographie*). 56 Vols., Leipzig, 1875–1912; reprinted Berlin, 1967–1971.

ANB (*American National Biography*). 24 Vols., Oxford University Press, 1999.

AMWS (*American Men and Women of Science: A Biographical Directory*). New York, 1906–. (Prior to 12th edition (1971) entitled *American Men of Science*).

AO (*Athenae Oxonienses*), A New Edition. A facsimile of the London edition of 1813, Anthony Wood, 4 Vols., Reprint, New York and London, 1967.

B-DH (*Dictionnaire historique et critique*), Pierre Bayle, 4 Vols., Rotterdam, 1720.

BDAS (*Biographical Dictionary of American Science: The Seventeenth Through the Nineteenth Centuries.*), edited by Clark A. Elliott, Westport, 1979.

BDS (*Biographical Dictionary of Scientists*), 3rd ed., edited by Roy Porter and Marilyn Bailey Ogilvie, 2 Vols., New York, 2000.

BGA (*Bibliographie générale de l'astronomie*), edited by J.C. Houzeau de Lehaie and A.B.M. Lancaster, 3 Vols., Brussels, 1887–1889.

BK (*Bibliografia Kopernikowska 1509–1955*), edited by Henryk Baranowski, Reprint, New York, 1970.

BLH [P] (*Biographisch-literarisches Handworterbuch zur Geschichte der exakten Wissenschaften.*), edited by J. C. Poggendorff, Leipzig and Berlin, 1863–1926. Band VIIa -Supplement. Berlin, 1969.

BNB Académie Royale de Belgique. (*Biographie Nationale Belgique*), 20 Vols., Brussels, since 1866–.

BU (*Biographie Universelle, Ancienne et Moderne*) *ou* (*Histoire, par ordre alphabétique : de la vie publique et privée de tous les hommes qui se sont fait remarquer par leurs écrits, leurs actions, leurs talents, leurs vertus ou leurs crimes.*), J-F Michaud, 85 Vols., in 45 Vols. Paris: Michaud Frères, 1811–1862. *Second, revised edition*. (variants)

BWN (*Biographisch Woordenboek der Nederlanden*), 21 Vols., Haarlem,1852–1878.

CBD (*Chambers' General Biographical Dictionary*), 32 Vols., London, 1812–1817 (1984)

CA (*Alumni Cantabrigienses: A Biographical List of All Known Students, Graduates and Holders of Office at the University of Cambridge to 1900*), J. Venn, 10 Vols., Cambridge University Press, Cambridge, 1922–1954.

DAB (*Dictionary of American Biography*), 20 Vols., New York, 1928–1936; reprinted in 10 Vols. with supplements, New York.

DBF (*Dictionnaire de Biographie Française*), edited by J. Balteau *et al.*, with supplements, Paris, 1932–.

DBI (*Dizionario Biografico Degli Italiani*) (currently 59 Vols., Rome, 1960–).

DNB (*Dictionary of National Biography*), edited by Sir Leslie Stephen *et al.*, 72 Vols., 1885–1912 (1964); See **ODNB** below.

DSB (*Dictionary of Scientific Biography*). Charles Scribner's Sons, New York, edited by Charles Coulston Gillispie (Vols. I-XVI) and Frederic L. Holmes (Vols. 17–18). (Volumes I-XIV: 1970–1976; Volume XV: *Supplement I*, 1978; Volume 16: *Index*, 1980; Volumes 17–18: *Supplement II*, 1990.)

EC (*Encyclopedia of Cosmology*), edited by Norriss S. Hetherington, New York, 1993.

FS (*Les Femmes dans la Science*). Notes Recueillies by Alononse Rebiere, 2nd Edition, Paris, 1897.

G-HC (*A Historical Catalogue of Scientific Periodicals*) (*1665–1900*), New York, 1985.

HEA (*History of Astronomy: An Encyclopedia*), edited by John Lankford, New York, 1997.

ICB (*ISIS Cumulative Bibliography*). *A Bibliography of the History of Science formed from ISIS Critical Bibliographies 1–90, 1913–1965*, Vols., 1–2 (Personalities). London, 1971, *et seq.* (Critical Bibliographies 1–90 (1913–1965), 6 Vols.; 91–100 (1966–1975), 2 Vols.; 101–110 (1976–1985), 2 Vols.; (1986–1995), 4 Vols.

M (*Biographie universelle ancienne et moderne,* publiée par Michaud), Joseph-François Michaud, Paris, 1810–1828, 52 Vol. in-8, plus 32 Vols. supplément.

ML (Louis Moréri, *Le grand Dictionaire historique, ou le mélange curieux de l'histoire sacrée et profane*), Lyon, 1671 *et seq.*

N (Jean-Pierre Nicéron, *Mémoire pour servir a l'histoire des hommes illustres dans la République des Lettres, avec un catalogue raisonne de leurs ouvrages*), 43 Vols., Paris, 1727–1745.

NBG (*Nouvelle Biographie Générale, Depuis les temps les plus reculés jusqu'à nos jours*), 46 Vols. in 24, Paris: Firmin Didot, 1853–66, edited by F. Hoeffer, variants.

NBU (*Nouvelle Biographie Universelle*) (title variants) 46 Vols., Paris, 1852–1866; reprinted in 23 Vols., Copenhagen, 1963–1969.

NDB (*Neue Deutsche Biographie*), edited by Historischen Kommission of the Bayerischen Akademie der Wissenschaften, 7 Vols., *et seq.*, Berlin, 1953–.

ODNB (*Oxford Dictionary of National Biography*), 61 Vols., Oxford, 2004.

P-BLH (*Biographisch-literarisches Handworterbuch der exakten Naturwissenschaften*), Johann C. Poggendorff *et al.*, Leipzig: Barth, 1863–1904; Leipzig, 1925–1940; Berlin, 1955–. (Variant titles), Reprinted: Band 1–6, to 1931. Ann Arbor, 1945.

RS (Royal Society of London, *Catalogue of Scientific Papers, 1800–1900*). London, 1867–1902; Cambridge, 1914–1925, 19 Vols.

SBB (*Scientists since 1660: A Bibliography of Biographies*), edited by Leslie Howsam, Brookfield, Vermont, 1997.

SCB-l (*A Short-title Catalogue of Books printed in England . . . 1475–1640*), edited by A.W. Pollard and G.R. Redgrave, London, 1926.

SCB-2 (*Short-title Catalogue of Books printed in England . . . 1641–1700*), edited by D.G. Wing, 3 Vols., New York, 1945–1951.

W-BD (*The Biographical Dictionary of Women in Science*), edited by Marilyn Ogilvie and Joy Harvey, 2 Vols., New York and London, 2000.

WS (*Women in Science, Antiquity through the Nineteenth Century: A Biographical Dictionary with Annotated Bibliography*), edited by Marilyn Bailey Ogilvie. Boston, 1986.

WS-A (*American Women in Science: A Biographical Dictionary*), edited by Martha J. Bailey, Santa Barbara, 1994.

WSI (*Women Scientists From Antiquity to the Present: An Index*), edited by Caroline L. Herzenberg, West Cornwall, CT, 1986.

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AO (*Oeuvres complètes de d'Alembert*), Alembert, Jean Le Rond d', Paris, 1821–1822, Reprint 1967.

AOP (*Oeuvres philosophiques, historiques et littéraires de d'Alembert*), Alembert, Jean Le Rond d', 18 Vols., Paris, 1805.

BBO (*Jacobi Bernoulli, Basileenis, Opera*), Jacob Bernoulli, (1654–1705), 2 Vols., Geneva, 1744.

BF-W (*Works of Francis Bacon*), Francis Bacon, edited by J. Spedding, R.C. Ellis, and D.D. Heath, 14 Vols., London, 1857–1874.

BRC (*The Correspondence of Robert Boyle*), Robert Boyle, edited by Michael Hunter, Antonio Clericuzio, and Lawrence M. Principe, 6 Vols., London, 2001.

BRW (*The Works of Robert Boyle*), Robert Boyle, edited by Michael Hunter and Edward B. Davis, Pickering and Chatto Ltd, 14 Vols., London, 1999–2000.

BRW-B (*The Works of the Honourable Robert Boyle*), To which is prefixed The Life of the Author, Robert Boyle, edited by Thomas Birch, 5 Vols., in folio, London, 1744; "A New Edition," 6 Vols., London, 1772.

C (*Nicholas Copernicus' Complete Works*), Nicolas Copernicus, edited by Jerzy Dobrzycki, translation and commentary by Edward Rosen, 4 Vols., London and Basingstoke, 1978–.

CC (*Carteggio*), Bonaventura Cavalieri, edited by Giovanna Baroncelli, Florence, 1987.

COO (*Opera Omnia*), Girolamo Cardano, 10 Vols., Reprint, New York and London, 1967.

DC (*Correspondance*), René Descartes, edited by Charles Adam and Gaston Milhaud. 8 Vols., Paris, 1936–1963.

DGG (*Le Opere dei Discepoli di Galileo Galilei*), Carteggio, Edizione Nazionale, Vol. 1 (1642–1648), Vol. 2 (1649–1656), edited by Paolo Galluzzi and Maurizio Torrini, Florence, 1975, 1984.

DO (*Oeuvres de Descartes*), René Descartes, edited by Charles Adam and Paul T. Tannery, 13 Vols., 1897–1913.

DSP (*Scientific papers*), George Howard Darwin, Cambridge, 1907–1916.

EC (*Correspondance mathématique et physique de quelque célèbres géomètres du XVIII*$^{\text{eme}}$ *siècle*), Leonard Euler, edited by P.H. Fuss, 2 Vols., St. Petersburg, 1843.

ECP (*The Collected Papers of Albert Einstein*), Princeton University Press, Princeton, 1987–.

EO (*Leonhardi Euleri Opera Omnia*), Leonard Euler, edited by Charles Blanc, Asot T. Grigorijan, Walter Habicht, Adolf P. Juskevic, Vladimir I. Smirnov, Ernst Trost, 3 Vols. Basil, 1975 (1911).

EO-2 (*Leonhardi Euleri Opera Omnia*), *Series prima* (*Opera mathematica*, 29 in 30 Vols.), *Series secunda* (*Opera mechanica et astronomica*, 31 in 32 Vols.), *Series tertia* (*Opera physica et Miscellanea*, 12 Vols.), *Series quarta A* (*Commercium epistolicum*, 9 Vols.), and *Series quarta B* (*Manuscripta*, approx. 7 Vols.), Basel, Birkhäuser, 1911–1996.

ESO (*Early Science in Oxford*), edited by R.T. Gunther, 14 Vols., Oxford, 1923–1945.

FGL (*The Gresham Lectures of John Flamsteed*), John Flamsteed, edited by Eric G. Forbes, London, 1975.

FO (*Oeuvres de Fermat*), Pierre Fermat, edited by Paul Tannery, Charles Henry, and Cornelis de Waard, 5 Vols., Paris, 1891–1922.

FOM (*Varia opera mathematica D. Petri de Fermat / accesserunt selectae quaedam ejusdem epistolae, vel ad ipsum a plerisque doctissimis viris Gallice, Latine, vel Italice, de rebus ad mathematicas disciplinas, aut physicam pertinentibus scriptae*), Pierre Fermat, Toulouse, 1679.

GAC (*Amici e corrispondenti di Galilei*), Galileo Galilei, edited by Antonio Favaro, with introductory notes by Paolo Galluzzi, 3 Vols., Florence (reprinted) 1983.

GGO (*Le Opere di Galileo Galilei*), Galileo Galilei, Edizione Nazionale, edited by Antonio Favaro, 20 Vols., Florence, 1890–1939.

GOO (*Petro Gassendi, Opera Omnia, hactenus edita auctor ante obit recensuit*), Pierre Gassendi, edited by H.L. Habert de Montmor and F. Henry, 6 Vols., Lyon, 1658–1675.

HC (*The Correspondence of Thomas Hobbes*), 2 Vols., Oxford, 1994.

HCP (*Correspondence and papers of Edmond Halley*), Edmond Halley, Oxford, 1932.

HD. (*The Diary of Robert Hooke MA., M.D., F.R.S. 1670–1680*), Robert Hooke, London, 1935.

HEW (*The English Works of Thomas Hobbes of Malmesbury*), Thomas Hobbes, edited by Sir William Molesworth, 11 Vols., London, 1839–1845.

HOC (*Oeuvres Complètes de Christiaan Huygens*), Christiaan Huygens, publiées par la Société Hollandaise des Sciences, 22 Vols., The Hague, 1888–1950.

HP (*The Hartlib Papers*), Samuel Hartlib, The Hartlib Project, directed by Michael Leslie, Mark Greengrass, Michael Hannon, Patrick Collinson, with assistance from Timothy Raylor, Judith Crawford and others, University of Sheffield. (CD-ROM edition)

IB (*Institut de France: index biographique des membres et correspondants de l'Académie des Sciences de 1666 a 1954*), Institute de France, Gauthier-Villars, Paris, 1954.

IBAC (*Académie des sciences. Index Biographique des Membres et Correspondants de l'Académie des Sciences*), Paris, 1968.

KA (*Joannis Kepleri astronomi opera omnia*), Johannes Kepler, edited by Christian Frisch, 8 Vols., Frankfurt, 1858–1871.

KGW (*Gesammelte Werke*), edited by Walther van Dyck, Max Caspar, and Franz Hammer. Munich, 1937–.

L (*The Correspondence of John Locke*), John Locke, edited by E.S. de Beer, 8 Vols., Oxford, 1976–1989.

L-CII (*Carteggio Linceo*), 3 parts, *Atti della Reale Accademia Nazionale dei Lincei, Memorie della Classe di Scienze Morali, Storiche e Filologiche* (*Part I anni* 1603–1609) pp 1–120, (*Part II, anni* 1610–1624, *Sezione I*, 1610–1615) Vol. 7, 1938 (XVI), pp 123–535; *Part II, Sezione II* (*anni* 1616–1624), pp 537–993; Part III (*anni* 1621–1630), pp 999–1446.

L-PG (*The Lives of the Professors of Gresham College*), John Ward, London, 1740; Reprint, New York and London, 1967.

LBO (*Bibliographie des Oeuvres de Leibniz*), edited by Emile Ravier, Hildesheim, 1966.

LCC (*Catalogue critique des manuscrits de Leibniz*), Gottfried Wilhelm Leibniz, edited by A. Rivaud, Poitiers, 1914–1924.

LMN (*Mathematischer Naturwissenschaftlicher und Technischer Briefwechsel*), Gottfried Wilhelm Leibniz, 2 Vols., (1663–1683) Berlin, 1976–1987.

LO. (*Oeuvres de Lagrange*), Joseph-Louis Lagrange, Paris, 1867–1892. Also, *Oeuvres*, Paris, 1973.

LOC (*Oeuvres complètes*), Pierre-Simon Laplace, 14 Vols., Paris, 1878–1912.

LR (*Register zu Gottfried Wilhelm Leibniz Mathematische Schriften und Der Briefwechsel mit Mathematikern*), Gottfried Wilhelm Leibniz, edited by Joseph Ehrenfried Hofman, Hildesheim and New York, 1977.

LSB (*Samtliche Schriften und Briefe*), Gottfried Wilhelm Leibniz, Damstadt, Leipsig, Berlin, 1923–.

LUI (*Lettre inedite di uomini illustri*), edited by Angelo Fabroni, 2 Vols., Florence, 1773 and 1776.

MAS (*Mémoires de l'Académie Royale des sciences depuis 1666 jusqu'à 1699*), 9 Vols., Paris, 1729–1732.

MC (*Correspondance du P. Marin Mersenne*), P. Marin Mersenne, edited by Paul Tannery, Cornelis de Waard, and Armand Beaulieu, 16 Vols., Paris, 1932–1986.

M-CL (*Collected letters of Colin MacLaurin*), Colin MacLaurin, Nantwich, Cheshire, England, 1982.

MCL (*Carteggio Magliabechi, Lettere di Borde, Arnaud e associati Lionesi ad Antonio Magliabechi* (*1661–1700*)), Antonio Magliabechi, edited by Salvatore Ussia, Florence.

MO (*Oeuvres de Malebranche*), Nicolas de Malebranche, Vols. 18–19, (*Correspondance actes et documents*), edited by André Robinet, Paris, 1978.

MP (*The Mathematical Practitioners of Tudor & Stuart England*), E.G.R. Taylor, Cambridge, 1954.

MP2 (*The Mathematical Practitioners of Hannoverian England*), E.G.R. Taylor, 1714–1840, Cambridge, 1966.

MPBS (*Manuscript Papers of British Scientists, 1600–1940*), London, 1982.

NC (*The Correspondence of Isaac Newton*), Isaac Newton, edited by H.W. Turnbull, J. F. Scott, and A. Rupert Hall, Cambridge, 7 Vols., 1959–1977.

NMP (*The Mathematical Papers of Isaac Newton*), Isaac Newton, edited by Derek T. Whiteside, 8 Vols., Cambridge, 1967–1981.

OC (*The Correspondence of Henry Oldenburg*), Henry Oldenburg, edited by. A. Rupert Hall and Marie Boas Hall, 9 Vols., Madison, 1965–1973; Vols., 10 and 11, Mansell, London, 1975–1977; Vols., 12–13, Taylor and Francis, 1986.

P-C. (*Les Correspondants de Peiresc, Lettres inédites*), Nicolas-Claude Fabri de Peiresc, 2 Vols., Reprint, Geneva, 1972.

P-L (*Lettres de Peiresc*), Nicolas-Claude Fabri de Peiresc, edited by Philippe Tamizey de Larroque, 7 Vols., Paris, 1888–1898.

PDC. (*Diary and Correspondence of Samuel Pepys, F.R.S.*), Samuel Pepys, edited by Richard Braybrooke, 4 Vols., London, 1848–1849.

PHI (*Les Hommes illustres qui ont paru en France pendant le XVIIe siècle*), Charles Perrault, 2 Vols., Paris, 1696–1700.

PO (*Oeuvres de Blaise Pascal*), Blaise Pascal, edited by Leon Brunschvicg, Pierre Boutroux, and Felix Gazier, 14 Vols., Paris, 1908–1914.

POC (*Oeuvres complètes*), Blaise Pascal, preface by Henri Gouhier, notes by Louis Lafuma, editions du Seuil, Paris, 1963.

PT (*Philosophical Transactions: giving some Accompt of the present Undertakings, Studies and Labours of the Ingenious in many considerable parts of the World*), edited by Henry Oldenburg, London and Oxford, 1665–1677.

S-C (*The Correspondence of Spinoza*), Benedict de Spinoza, edited and translated by Abraham Wolf, London, 1928.

S-OP (*Opera Posthuma*) Benedict de Spinoza, edited by J. Jellis, Amsterdam 1677; Dutch edition, *Die nagelate Schriften van B. d. S.* (n.p., 1677).

SS (*The Principal Works of Simon Stevin*), Simon Stevin, edited by E.J. Dijksterhuis, D. J. Struik, A. Pannekoek, Ernst Crone, and W.H. Schukking, 4 Vols., Amsterdam, 1955–1964.

TBO (*Tychonis Brahe Dani Opera Omnia*), Tycho Brahe, edited by J.L.E. Dreyer, 15 Vols., Copenhagen, 1913–1929.

TO (*Opere di Evangelista Torricelli*), Evangelista Torricelli, edited by Gino Loria and Giuseppe Vassura, 4 Vols., in 5 pts, Faenza, 1919–1944.

Geographical Place Names in Biography Headers

Birth and death places are given as [city], [country] when well known, *e. g.*, London, England and Rome, Italy. Lesser-known places are often accompanied by regional/provincial/county/state names, *e. g.*, Beverley, Humberside, England and Lusigny, Aube, France. States in the USA, Canadian provinces, and Australian states are included.

All place names are given as they are found on current maps. Where city names have changed historically, the modern version follows the original within parentheses, *e. g.*, Constantinople (Istanbul, Turkey) and Pitschen (Byczyna, Poland). In cases where cities have disappeared, the nearest modern place is given, *e. g.*, Colophon (near Selcuk, Turkey).

Regional/provincial/county/state names as well as country names are placed within parentheses if they did not exist at the time of the subject's birth or death. Place names are given in the original language except where common English versions exist, *e. g.*, Milan, Germany, Bavaria, Tuscany, Munich, *etc*.

Richard A. Jarrell

A

ab Hayck

➤ **Hájek z Hájku, Tadeá**

ˁAbbās Wasīm Efendi

Born **Bursa, (Turkey), 1689**
Died **Istanbul, (Turkey), 1760**

ˁAbbās Wasīm Efendi was a scholar who made many valuable contributions to Ottoman astronomy. These included writing a Turkish commentary on the famous astronomical handbook (*Zīj*) of **Ulugh Beg** as well as translating **ˁAbd al-ˁAlī al-Bīrjandī**'s work on solar and lunar eclipses into Turkish. In addition to being an astronomer, he was a physician, a calligrapher, and a poet; he was also a member of the Khalwatiyya and Qādiriyya religious orders. Besides knowing Turkish, ˁAbbās Wasīm Efendi knew a number of languages that included Arabic, Persian, Latin, French, and ancient Greek.

ˁAbbās Wasīm Efendi, whose father's name was ˁAbd al-Raḥmān and whose grandfather's name was ˁAbdallāh, was known as Kambur (Humpback) Vesim Efendi and as Dervish ˁAbbās Ṭabīb. He pursued his education with eminent scholars; apparently his teachers appreciated his cleverness, aptitude, and open-minded attitude. His studies and research took him to Damascus, to Egypt, and to Mecca and Medina (where he performed the *ḥajj* or pilgrimage). Upon his return to Istanbul, ˁAbbās Wasīm Efendi opened a pharmacy and a clinic at the Yavuz Selīm Bazaar in the Fatiḥ district of Istanbul, where he treated patients for almost 40 years. He wrote and translated many works on medicine and pharmacology, incorporating the information he obtained through his many contacts with European physicians coming to Istanbul. From these contacts ˁAbbās Wasīm Efendi was able to learn Latin and French, translate Italian medical texts into Turkish, and closely follow advancements in medical science in Europe.

ˁAbbās Wasīm Efendi's main contribution to Ottoman astronomical literature is his translations and commentaries. Without any doubt, his most important work is his Turkish commentary on Ulugh Beg's *Zīj* (astronomical handbook), which was originally written in Persian and was used as the main reference book by the chief astronomers and timekeepers of the Ottoman State for their astrological and astronomical studies. ˁAbbās Wasīm Efendi began working on this book in 1745, at the request of the historian and astronomer Aḥmad Miṣrī, who convinced him of the importance of a Turkish translation. Upon completion, ˁAbbās Wasīm Effendi presented it to the Ottoman Sultan Maḥmūd I (reigned: 1730–1754). His commentary is written in clear Turkish, in the same style as **Mīram Chelebī**'s (died: 1525) commentary on the same work. The examples given in the book are all based on ˁAbbās Wasīm Effendi's own calculations for the longitude and latitude of Istanbul. He has included findings from ancient Turkish, Hebrew, and Roman Calendars, which were not in the original. He has also explained Ulugh Beg's method for finding the sine of 1°, which was based on the work of **Jamshīd al-Kāshī**. One may deduce that ˁAbbās Wasīm Effendi was interested and well-informed on astrology since he dedicates a separate and large section of the book to the subject.

A valuable work on solar and lunar eclipses that ˁAbbās Wasīm Efendi also translated into Turkish was Chapter Ten of Bīrjandī's *Ḥāshiya ˁala sharḥ al-Mulakhkhaṣ fī al-hay'a* (which was a supercommentary on **Jaghmīnī**'s elementary astronomical textbook). He titled his book *Tarjamat kitāb al-Bīrjandī min al-khusūf wa-'l-kusūf*.

Another astronomical work concerns lunar crescent visibility, which is important for religious observance. ˁAbbās Wasīm Efendi also wrote a work entitled *Risāla al-wafq* dealing with prognostication and astrology.

Salim Aydüz

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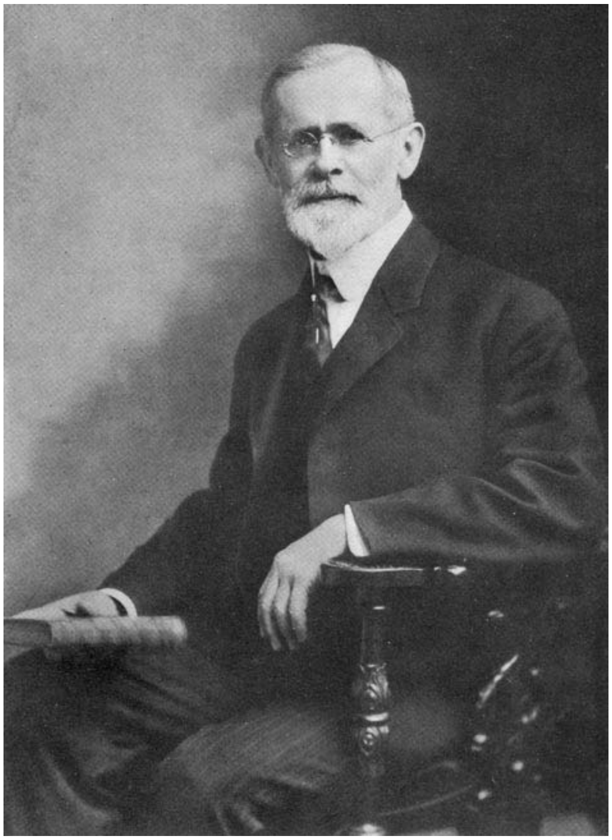
Abbe, Cleveland

Born **New York, New York, USA, 3 December 1838**
Died **Chevy Chase, Maryland, USA, 28 October 1916**



A practical astronomer, mathematician, and meteorologist, Cleveland Abbe is perhaps best noted as the father of weather forecasting in the United States, having produced the first storm forecasts while director of the Cincinnati Observatory. Abbe was the son of George Waldo, a dry-goods merchant and broker, and Charlotte (*née* Colgate) Abbe. The Abbe family emigrated from England in 1635, settling first in Connecticut. The family was prominent in the American Revolution and the American Civil War.

Cleveland Abbe's mother presented him with a copy of William Smellie's *Philosophy of Nature* when he was eight years old. This book awakened in the young boy a lifelong interest in the natural sciences. A voracious reader for his entire life, Abbe's early education was at a private school in New York City. He entered the New York Free Academy (now the City College of New York) at age thirteen, received his B.A. in 1857, and an M.A. in 1860.

Abbe became seriously interested in astronomy while he was a tutor in engineering at the University of Michigan in 1860. Inspired by **Franz Brünnow**, director of the Detroit Observatory, Abbe took up the study of astronomy.

However, Abbe's service at the University of Michigan was interrupted when he responded to President Lincoln's first call for volunteers for the American Civil War. Unfortunately, after several weeks in training Abbe was rejected because of his extreme myopia. Instead, Abbe went to Cambridge, Massachusetts, where he assisted **Benjamin Gould** in the telegraphic longitude work of the United States Coast Survey.

At the end of the war, Gould suggested that Abbe go to Pulkovo Observatory in Russia to study astronomy under **Otto Wilhelm Struve**. Abbe applied to Struve, who welcomed him with an invitation written in such warm terms that the document became one of Abbe's most treasured possessions. He spent 1865 and 1866 as a supernumerary astronomer (the equivalent of the modern postgraduate fellowship) at Pulkovo, where the Struves treated him as a family member. Abbe seriously considered settling at Pulkovo and marrying Struve's youngest half sister, Ämalie. However, Struve rejected Abbe's petition on the grounds that in the Struve's German culture, Ämalie, the youngest daughter, was expected to remain at home to care for her elderly stepmother. Within a few weeks, Abbe returned to the United States. He regarded his years at Pulkovo as the highlight of his career.

Upon his return to the United States, Abbe filled a short appointment at the United States Naval Observatory before assuming duties as director of the Cincinnati Observatory. During the 19th century, astronomical observatories often served as dispensers of more general scientific information to the public. In addition to astronomy, the citizens of Cincinnati wanted authoritative information on meteorology, geology, mathematics, chemistry, and physics. Abbe formulated an ambitious plan to embrace all of these disciplines during his tenure. However, he soon focused his activities on meteorology.

While working for Gould, Abbe saw how the telegraph could be a valuable modern tool in making precision simultaneous scientific observations. With the cooperation of the Cincinnati Chamber of Commerce and the Western Union Telegraph Company, he began to collect simultaneous weather observations from over 100 stations in 1869. Building a database from this information, he was soon able to make weather predictions for the eastern and midwestern United States. Abbe's work constituted the world's first large-scale weather prediction system. The predictions were published daily in hundreds of newspapers. The results of the network were so favorable that within 6 months Western Union took the system over as one of its services. Shortly after that, the United States government assumed control of the operation, assigning it to the United States Army Signal Corps. The service was known as the United States Weather Bureau. Abbe edited weekly and monthly weather reports for the bureau for 45 years, beginning in 1871. The bureau eventually evolved into today's National Oceanic and Atmospheric Administration.

Abbe was a man of great modesty, never touting his achievements. He was always willing to give encouragement and advice to those who worked or corresponded with him. He was particularly talented at mediating between the rigid hierarchy of the military chain of command and the more casual working methods of the scientists. His colleagues noted that he was totally devoid of any hint of envy or jealousy, a rare characteristic for a modern scientist!

Abbe was a skilled mathematician, geodesist, chemist, physicist, and engineer though his primary impact on science was in the field of meteorology. He was active in the field of astronomy for his entire life. Abbe was particularly interested in the effects of the atmosphere on astronomical observations. He was multilingual, and many of his most important contributions were compilations of translated materials on astronomy and meteorology. He was an early advocate of the standard time system, and represented the United States at the International Meridian and Time Standard Congress in Washington in 1884.

Abbe received an honorary Ph.D. from the College of the City of New York in 1891, honorary LL.D.s from the University of Michigan (1889) and the University of Glasgow (1896), and an honorary S.B. from Harvard University (1900). He received many medals, awards, and other honors, including the Franklin Institute's Longstreth Medal of Merit, the United States National Academy of Sciences' Marcellus Hartley Memorial Medal, and the American Philosophical Society's Franklin Medal. He was an *Officier d'Académie* of the French Republic, and a fellow of the Royal Astronomical Society.

Intensely intellectual, Abbe continued to work on his papers and correspondence until the week of his death. He was a prolific writer. There are over 5,500 items in his collected articles, papers, and books, which occupy 15 feet of shelf space in the Library of Congress.

Professor Abbe married Frances Martha Neal of Ohio (1870), and after her death, Margaret Augusta Percival (1909). He had three sons, Cleveland, Jr., Truman, and William. His brother, Richard, was a prominent New York surgeon who pioneered the use of radium and catgut sutures. Abbe was a devout Christian, and attended services of several Protestant denominations at different periods of his life.

Leonard B. Abbey

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Abbo of [Abbon de] Fleury

Flourished **France, *circa* 945–1004**

Abbo of Fleury constructed a novel diagram showing planetary positions as a function of time.

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Abbot, Charles Greeley

Born **Wilton, New Hampshire, USA, 31 May 1872**
Died **Washington, District of Columbia, USA, 17 December 1973**

Charles Abbot refined the value of the solar constant and significantly improved the technology of its measurement, but failed in his long-term effort to correlate small variations in the solar constant with terrestrial weather patterns. Abbot provided critically needed encouragement and financial support from both institutional and private sources to Robert H. Goddard's early research and development of liquid-fueled rocket technology.

The son of Harris and Carol Ann (*née* Greeley) Abbot, Charles studied chemistry and physics at Phillips Andover Academy, Massachusetts, and at the Massachusetts Institute of Technology, receiving an M.S. degree in 1895 for a thesis on osmotic pressure.

Although he knew nothing about astronomy at the time, Abbot was employed following his graduation by **Samuel Langley**, director of the Smithsonian Astrophysical Observatory [SAO] and secretary of the Smithsonian Institution. Abbot's work as Langley's aide at the SAO was focused on determination of the solar constant, a measure of the amount of energy received per unit area of the Earth's surface. Langley's preoccupation with this measurement reflected his intent to not only detect variations in that important physical parameter, but also establish correlations between variations in the solar constant and changes in the Earth's weather if possible. Toward that end, Langley had developed the bolometer and other measurement devices and made preliminary measurements of the solar constant, establishing a value of 3 cal cm^{-2} min^{-1}. Abbot replaced Langley as the SAO director upon the latter's death in 1905 and continued his mentor's research programs until his own retirement in 1944. An ingenious experimenter, Abbot developed a series of highly specialized instruments for measuring and characterizing solar energy reaching the Earth, and deployed these instruments at stations located on several continents. His first efforts in the city of Washington concentrated on eliminating sources of error in the measurement of the solar constant through improvements in the measuring device, which **Claude Pouillet** had named the pyrheliometer. Measurements with a refined pyrheliometer from Mount Wilson and Mount Whitney, both in California, led Abbot to reduce Langley's value to 2.1 cal cm^{-2} min^{-1} in 1907, with an eventual further reduction to 1.94 cal cm^{-2} min^{-1} after several decades of refined measurements and analysis of the data. Abbot recognized that daily measurements were essential to establish any correlation with weather, and further that measurements had to be made in elevated locations with a maximum of cloudless days and atmospheres clear of any pollution. This led to the establishment and operation of a series of SAO stations on mountains in Chile, Mexico, Algeria, South Africa, and the Sinai Desert as well as in New Mexico and California, USA.

Although Abbot's program of data gathering was endorsed at various times by distinguished scientists, including astronomers **George Hale**, **William Campbell**, and **Walter Adams**, as well as physicists **Robert Millikan** and Karl Taylor Compton (1887–1954), and meteorologists C. F. Marvin and H. H. Clayton, there was little agreement that his efforts to correlate small variations in the measured solar constant with weather patterns showed any significant results.

Abbot also developed powerful spectrographs with Langley's bolometers as sensitive radiation detectors. Using these spectrographs, Abbot mapped the solar spectrum in significant detail. On the basis of his results, by 1911 Abbot had concluded, correctly, that the continuous spectrum of the Sun could only be attributed to gas under high pressure, and further that the opacity of that gas would account for the apparent sharp edge of the solar photosphere. Abbot's finding contradicted a previous widely held belief that the photosphere consisted of incandescent solids and liquids.

In his role as home secretary of the United States National Academy of Sciences, Abbot arranged the 1920 William Ellery Hale lectures on the distance scale of the Universe, now known as the Curtis-Shapley debate. Hale was the father of **George Hale**, who had suggested the topic to Abbot.

In 1928, Abbot accepted additional administrative responsibility as the secretary of the Smithsonian Institution, which he undertook without yielding his position as director of the SAO. Abbot's tenure as secretary was dominated by the financial uncertainty endemic in all such institutions during the world economic depression and later during World War II. As a result of both these financial problems and to some extent from Abbot's benign neglect in favor of solar research, development of the Smithsonian Institution was largely stagnant during his service as secretary.

During these years, however, Abbot managed to arrange limited financial support for the rocket research of Robert H. Goddard, who had first contacted the Smithsonian Institution in 1916. Working both with Smithsonian Institution funds and with private support from philanthropist John A. Roebling, Abbot managed to eke out sufficient funds to support Goddard's research until military as well as scientific applications of the liquid-fueled rocket became attractive. Goddard served as a director of Roebling's foundation, The Research Corporation, in New York City from 1928 to 1945.

The practical aspect of Abbot's abilities was revealed in his record of inventions. He patented at least 16 inventions, many of which involved applications of solar energy. Abbot actively promoted the use of solar energy in his popular lectures and popular writing. His commitment to popularizing science was also reflected in the publication of the Smithsonian Scientific Series of popular books on science and technology.

In 1915 Abbot was elected to membership in the National Academy of Sciences, having received the Academy's Draper Medal in 1910. His peers in the American Academy of Arts and Sciences [AAAS] honored him with the Rumford Medal in 1916 and elected him as AAAS fellow in 1921. Abbot was the recipient of honorary doctorates from a number of universities including D.Sc.s from the University of Melbourne (1914), the Case School of Applied Science (1930), and George Washington University (1937), and an L.L.D. from the University of Toronto (1933).

In 1897, Abbot married Lillian E. Moore, who died in 1944. He was survived by his second wife, Virginia A. Johnston, whom he married in 1954.

Thomas R. Williams

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Abbott, Francis

Born **Derby, Derbyshire, England, 12 August 1799**
Died **Hobart, Tasmania, (Australia), 18 February 1883**

Francis Abbott's important contributions to Tasmanian and Australian astronomy and meteorology were overshadowed by his controversial claim to have observed shrinkage of the η Carinae nebula that he believed was evidence of the evolution of a stellar system like our Solar System.

Abbott, the son of John and Elizabeth Abbott, was baptized on 12 August 1799. Trained as a watchmaker in Derby, he established his business there and, in 1825, married Mary Woolley; they had seven children. In 1831 Abbott moved to Manchester where he ran a successful business manufacturing clocks, watches, and astronomical machinery until 1844 when he was found guilty of obtaining two watches under false pretences. Sentenced to penal servitude, he arrived in Hobart in June 1845, and after 4 years obtained his ticket-of-leave and set up as a watch- and clockmaker in Hobart. With the passage of time his business expanded to include photography and the supply and repair of optical and other instruments. Despite his less than auspicious arrival in the colony, Abbott and his family (who arrived in 1850) became respected members of Tasmanian society, with three of his sons rising to positions of prominence.

During the 1840s Hobart lacked an astronomical observatory, but it did boast of a geomagnetic and meteorological observatory. While still a convict, Abbott became involved in the Rossbank Observatory's meteorological program. When the observatory closed at the end of 1854, Abbott – by now a free man – immediately established a private observatory at his home in Hobart and continued his meteorological observations. For the next 25 years he authored monthly reports on his thrice-daily readings, and six monographs that documented Hobart's weather from 1841 to 1879 inclusive. These volumes were published, with funding from the government, by the Royal Society of Tasmania [RST]. Abbott's private observatory included, apart from its full suite of meteorological instruments, a small transit telescope and an astronomical clock. For nearly 30 years he provided a local time service.

Abbott's observatory was best known for its astronomical output. With the aid of three small refracting telescopes (the largest with an aperture of about 13 cm), he observed a succession of comets and current phenomena including the variable star η Carinae. Abbott published 35 papers in *Monthly Notices of the Royal Astronomical Society*, *Papers and Proceedings of the Royal Society of Tasmania*, and the *Astronomical Register* on the 1861 and 1868 transits of Mercury, the 1874 transit of Venus, sunspots and aurorae, a lunar occultation of Jupiter, meteors, the open cluster κ Crucis, and a number of comets. Apart from providing invaluable data on the Great Comet of 1861 (C/1861 J1), which was discovered by **John Tebbutt**, Abbott also wrote three papers about the Great Comet of 1865 (C/1865 B1), of which he made an independent discovery – although he is generally not given credit for this.

In contrast to his comet work, it was his observations of η Carinae that brought Abbott international notoriety. He began recording the declining magnitude of this enigmatic variable star in 1856. However, in an 1863 paper in *Monthly Notices*, Abbott postulated that the nebulosity surrounding the star had changed in shape and size since Sir **John Herschel** first observed the region in the 1830s. Abbott's claim ran counter to the prevailing wisdom and elicited objections from Herschel and other distinguished Northern Hemisphere astronomers, including Astronomer Royal **George Airy**. Abbott continued to press his claim in 13 further papers published until 1871, when the respected astronomer–popularizer, **Richard Proctor**, was asked to adjudicate on the matter. Proctor's report was damning:

> Mr. Abbott has supposed the dark spaces (shown in Sir J. Herschel's Monograph) to correspond to the lemniscate, which would unquestionably imply a complete change in the whole aspect of the Nebula. [But] On the scale of Mr. Abbott's drawings, the lemniscate would be about 2/5ths of an inch long; it would, in fact, be a minute and scarcely discernible feature (Richard Proctor).

In spite of Proctor's finding, Abbott published two further papers on the topic before finally bowing to international pressure. Although he did record one of the contact times for the 1874 transit of Venus, the unfortunate η Carinae episode all but terminated Abbott's credibility. After 1873 no further papers by him appeared in European astronomical journals.

Instead, Abbott turned his considerable energy and enthusiasm to the popularization of astronomy. In quick succession he published three short booklets privately to bring recent international developments in astronomy before an Australian audience. Spectroscopy in general and astronomical spectroscopy in particular feature prominently in the first two works, while the third booklet highlights Sir **William Herschel**'s important overall contribution to astronomy. In view of the aforementioned η Carinae controversy, it is interesting that this star is scarcely mentioned in any of the booklets. Abbott resisted introducing any semblance of a local flavor into these booklets, not mentioning either his own astronomical endeavors or those of Tebbutt and some of Australia's leading professional astronomers.

Apart from his prominence as a maker of public clocks, from 1855 to 1880, Abbott served as Tasmania's *de facto* government astronomer and meteorologist. It was only when advancing age made him relinquish this gratuitous role that the RST argued for the urgent need for a colonial observatory. As a result, the government opened the Hobart Observatory in 1882 under the directorship of Captain Shortt; its charter included timekeeping, meteorology, and astronomy.

Abbott was an active member and councilor of the Royal Society of Tasmania, and was elected a fellow of both the Royal Astronomical Society and the Royal Meteorological Society.

Wayne Orchiston

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ˁAbd al-Wājid: Badr al-Dīn ˁAbd al-Wājid [Wāḥid] ibn Muḥammad ibn Muḥammad al-Ḥanafī

Born **Mashhad, (Iran)**
Died **Kütahya, (Turkey), 1434**

ˁAbd al-Wājid was a *mudarris* (teacher) who wrote several works on astronomy that indicate that he was greatly influenced by the astronomical educational tradition of the Marāgha circle of scholars (including **Ṭūsī** and **Shīrāzī**). He traveled to Anatolia from his native region of Khurāsān in Iran, and became a student of Muḥammad ibn Ḥamza al-Fanārī (died: 1431) during the reign of Germiyānoğlu Süleymān Shāh (1368–1387). ˁAbd al-Wājid later settled in Kütahya and taught at the Wājidiyya Madrasa (known as the Demirkapi Madrasa during the Ottoman Period) until his death. The influence of the Marāgha circle had previously been felt in Anatolia because of Shīrāzī, who had also worked at various centers and schools there.

Local traditions indicate that the Wājidiyya Madrasa was a place where astronomical observation and instruction took place, often associated with ˁAbd al-Wājid in the 14th century. According to its foundation inscription, this *madrasa* was built in 1308 by Mubāriz al-Dīn ibn Sāwjī. ˁAbd al-Wājid must have been a very prominent professor at this *madrasa* in as much as it seems to have been renamed in his honor; clearly, he was not one of its founding professors. Because ˤAbd al-Wājid had astronomical interests and was the author of several books on astronomy, the local tradition connecting the school with astronomy gains some credibility. This probably consisted of astronomical instruction and some practical applications. It is unlikely, though, that there was a large-scale observatory, such as those at Marāgha and Samarqand, associated with the school.

Among ˤAbd al-Wājid's works on astronomy, *Sharḥal-Mulakhkhaṣ fī al-hay'a* is a commentary on **Jaghmīnī**'s famous astronomical textbook; ˤAbd al-Wājid dedicated it to Sultan Murād II (1404–1451). *Sharḥ Sī faṣl* is a commentary on Ṭūsī's Persian work on practical astronomy, which consists of 30 chapters. This text was translated into Turkish by Ahmed-i Dāˤī, but it cannot be precisely dated. *Maˤālim al-awqāt wa-sharḥuhu* is a work about the astrolabe and its uses. It was written in verse and consisted of 552 couplets. It was dedicated to Muḥammad Shāh (died: 1406), the son of ˤAbd al-Wājid's teacher al-Fanārī.

Hüseyin Topdemir

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Abetti, Antonio

Born **Gorizia, (Friuli-Venezia Giulia, Italy), 19 June 1846**
Died **Arcetri near Florence, Italy, 20 February 1928**

Italian astronomer Antonio Abetti revived the Arcetri Observatory south of Florence and made it one of the leading astrophysical institutions in Europe. He was a civil engineer and an architect but turned his interest to astronomy in 1868, almost immediately after he received a degree in mathematics and engineering from the University of Padua. He began his career at the local observatory, then headed by **Giovanni Santini**, as an assistant until 1893. After an examination Abetti was appointed director of the Arcetri Observatory and professor of astronomy at the University of Florence. In 1921, aged 75, he had to retire from the posts but continued his researches at the observatory.

The main field of Abetti's work was positional astronomy. During the 25 years in Padua he made many observations of small planets, comets, and star occultations, which he published in the *Memoirs and Observations of the Observatory of Arcetri* and in the *Astronomische Nachrichten*. On an expedition led by **Pietro Tacchini** to Muddapur, Bengal, India, in 1874, he observed the transit of Venus across the Sun's disk through a spectroscope. It was the first time that such an instrument was used for this purpose.

The Arcetri Observatory, founded by **Giovanni Donati** in 1872, had been partially abandoned after Donati's death. Then one of the first major tasks for Abetti was to erect a telescope that he had built in the workshops at Padua. The objective lens he used was the 28-cm (11 in.)-diameter achromatic doublet with 533 cm focal length constructed by **Giovanni Amici** in 1839. With this instrument Abetti and others obtained many observations on the positions of minor planets, comets, and stars.

Abetti was a member of the Accademia Nazionale dei Lincei (Rome), associate member of the Royal Astronomical Society (London), and a member of several other Italian academies. In 1879 he had married Giovanna Colbachini, of Padua; they had two sons. The younger son, **Giorgio Abetti**, shared his father's interest in astronomy and became an astronomer himself, succeeding his father as director of the Arcetri Observatory in 1921.

A lunar crater and minor planet (2646) Abetti are named to honor Antonio Abetti and his younger son.

Christof A. Plicht

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Abetti, Giorgio

Born **Padua, Italy, 5 October 1882**
Died **Florence, Italy, 24 August 1982**

Giorgio Abetti is most closely associated with detailed measurements and interpretation of the Evershed effect, sometimes called the Evershed–Abetti effect. He also played an important part in the development of astrophysics in Italy in the 1920s and 1930s, when most of the Italian observatories were focused on positional astronomy. Abetti obtained his degree in physics at the University of Padua in 1904, where his primary teacher had been his father, **Antonio Abetti**. He spent time at Yerkes, Heidelberg, Mount Wilson (where **George Hale** was one of his mentors), and Rome observatories (1910–1919). In 1921, he accepted appointments as professor of astronomy at the University of Florence and director of the nearby Arcetri Observatory, where he remained until his retirement in 1953.

While at Rome, Abetti made use of observations from many locations to show that the true diameter of Neptune is only 2.3″, and the density of the planet therefore is larger than had been supposed up to that time (1912). His primary interest was, however, in solar surface phenomena, and he managed to have built a 24-m-high solar tower at Arcetri in 1924. This was used to obtain spectra of small regions on the solar surface, particularly in and around sunspots. The Doppler shifts of the hydrogen and metallic lines from gas in and around the spots, when observed for spots at different locations on the Sun (so that the Doppler shift provides information about motions both perpendicular and parallel to the solar surface), showed the pattern of gas flows in solar active regions. In particular, Abetti's work revealed that the flow outward in spot areas is extremely variable in both space and time, ranging from almost 0 km s^{-1} to about 6 km s^{-1}, rather than being constant and regular as had previously been supposed. The Doppler shifts caused by these flows are now generally called the Evershed effect, but sometimes the Evershed–Abetti effect. Abetti's solar and other work appeared in more than 250 scientific papers and several books.

Abetti was one of the founders of the International Astronomical Union [IAU] at its first formal meeting in Rome in 1922, participating in several of the commissions devoted to solar studies. He later served as vice president of the IAU. Abetti was elected a corresponding member of the Accademia dei Lincei in 1926 and a national member in 1938 and was a founder (1920) and later president of the Società Astronomica Italiana. He was also active in early work in the attempt to understand solar–terrestrial relations – the relationship between solar activity and the magnetic field, aurorae, weather, and other earthly phenomena. Abetti was the first chair of an IAU committee, organized in 1928, to monitor various solar-activity indicators and to collect and publish the data.

Abetti's influence in Italian astronomy and astrophysics continued through his students and junior colleagues. These (and the observatories they later directed) have included, in chronological order, Attilio Colacevich (Naples), Guiglielmo Righini (Arcetri, in succession to Abetti), Giulio Calamai, **Mario Fracastoro** (Catania and Pino Torinese), Vinicio Barocas, Maria Ballario, Margherita Hack (Trieste), Giovanni Godoli (Catania), and Mario Rigutti (Catania).

Margherita Hack

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Abharī: Athīr al-Dīn al-Mufaḍḍal ibn ʿUmar ibn al-Mufaḍḍal al-Samarqandī al-Abharī

Born **probably Mosul, (Iraq)**
Died **Shabustar, (Iran), possibly 1265**

Abharī, sometimes referred to as "Athīr al-Dīn al-Munajjim" (the astrologer), was a well-known philosopher who wrote influential texts in logic, mathematics, and astronomy. There has been diverse speculation about where and when Abharī was born, with the predominant opinion being that he was born in Mosul. "Samarqandī" in his name indicates that either he or his ancestors originally stemmed from there, most likely belonging to the Abhar tribe.

Little information is known about Abharī's education. It is thought that he attended primary school in Mosul and later traveled to the scientific and cultural centers in Khurāsān, Baghdad, and Arbil to continue his studies. The biographer Ibn Khallikān reports that Abharī took part in the assemblies of the famous scholar Kamāl al-Dīn ibn Yūnus (died: 1242) and even worked as his assistant at the Badriyya School in Mosul. Other reports claim that Abharī was a student of the renowned theologian Fakhr al-Dīn al-Rāzī (died: 1210), that he taught at the Sharafiyya School in 1248 in Baghdad, that he traveled to Iran from Mosul, that he lived for a time in Sivas in Anatolia, and that he eventually died of paralysis in Azerbaijan.

Abharī was an important figure in Islamic intellectual history not only because of his writings but also because of his teaching and interactions with scholars of the period. Among his students were the famous historian Ibn Khallikān (already mentioned), the philosopher Najm al-Dīn al-Kātibī, and Shams al-Dīn Muḥammad al-Iṣfahānī. He also had fruitful exchanges with the cosmologist ʿImād al-Dīn Zakariyyā ibn Maḥmūd al-Qazwīnī and the famous astronomer and polymath **Naṣīr al-Dīn al-Ṭūsī.**

Abharī studied astronomy under Kamāl al-Dīn ibn Yūnus, and his keen interest in the subject, as well as a desire to produce textbooks, led Abharī to deal with astronomy in several of his works. For example, he devoted the second part of the third chapter of his work, *Kashf al-ḥaqāʾiq fī taḥrīr al-daqāʾiq*, to astronomy. There he accepts the widely held view that the celestial bodies do not undergo the changes found in the sublunar realm, such as division or rejoining, diminution or growth, expansion or contraction, and so forth. He also maintains that stars are alive and have volition, which was the ultimate source of their motion.

Abharī's independent astronomical works include treatises on the astrolabe, commentaries on earlier *zīj*es (astronomical handbooks with tables), and compendia on astronomy. In the latter category, we find a *Risāla fī al-hayʾa* (Treatise on astronomy; extant in Istanbul, Süleymaniye, H. Hüsnü MS 1135) and a *Mukhtaṣar fī al-hayʾa* (Epitome of astronomy, extant in Istanbul, Süleymaniye, Carullah MS 1499). Both contain standard expositions of the cosmography of the orbs (*aflāk*), spherical astronomy, planetary motion, and the characteristics of the terrestrial climes. This *Mukhtaṣar* includes 22 sections and 119 figures, and is said to be an epitome of astronomical works by **Kūshyār ibn Labbān** and **Jābir ibn ʿAflaḥ**.

Abharī wrote several mathematical works, including a "Correction" (*Iṣlāḥ*) of Euclid. Among the "corrections" is an attempt to prove the parallels postulate. This was quoted in later works, in particular by **Samarqandī**, who was critical of Abharī's proof. In both mathematics and astronomy, Abharī seems to have had a significant influence on science during the Ottoman Period.

Hüseyin Sarıoğlu

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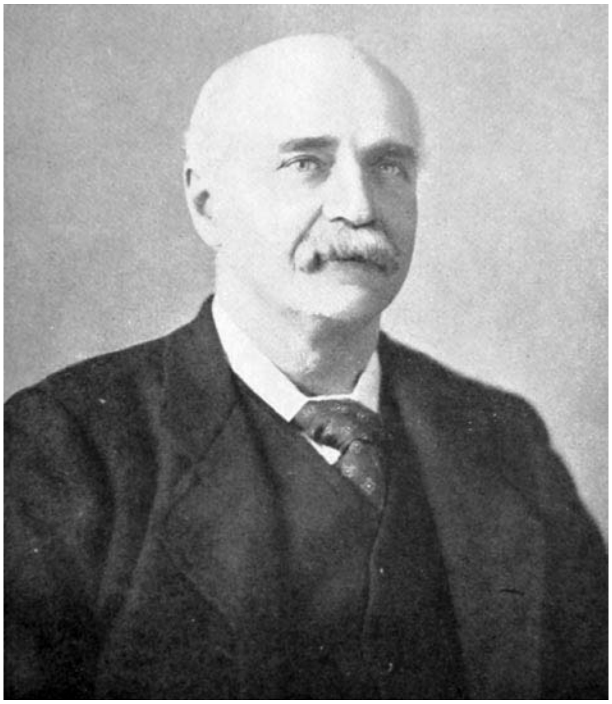
Abney, William de Wiveleslie

Born **Derby, England, 24 July 1843**
Died **Folkestone, Kent, England, 2 December 1920**



Sir William Abney was a notable pioneer in scientific photography, and his interests included the application of photography to astronomy. He was the son of Canon E. H. Abney, and was educated at the Rossall School. William received military training in the British army at the Royal Military Academy from 1861, entered the Royal Engineers as a lieutenant in 1861, and served briefly in India. After his return, Abney was employed as an instructor at the School of Military Engineering, Chatham, Kent, where he came to be in charge of a photographic and chemical laboratory. Here his pioneering experiments in scientific photography were initiated, and also his deep interest in astronomy was kindled from this time. He became a fellow of the Royal Astronomical Society in 1870, and was promoted to the rank of captain in the Royal Engineers in 1873.

Abney, along with **Hermann Vogel** and others, pioneered the introduction of dry-gelatin photographic plates in astronomy, and Abney attempted using them for the transit-of-Venus observations of 1874, from Egypt. His most famous scientific work was undoubtedly his development of infrared-sensitive photographic emulsions, produced by mixing gum resins with collodion, for a silver bromide emulsion. This work was undertaken at Chatham from 1875 and allowed Abney to photograph the solar spectrum to 1.2-μm wavelength and catalog lines to beyond 1 μm. The labeling of several strong solar spectral lines, including labeling of the infrared calcium triplet as x_1, x_2, and x_3, are from this work, as is the first use of the term “infrared.” The Bakerian Lecture to the Royal Society, London, in 1880 reported on this achievement in solar-spectrum photography.

One further notable astronomical paper of these years concerns Abney’s prediction, in 1877, that fast-rotating stars should have broadened nebulous lines, as a result of the opposite signs of the line-of-sight velocities from each limb causing the overall effect of Doppler line broadening. This hypothesis was at first rejected by the distinguished German astronomer Vogel in Potsdam, who believed line broadening was limited to selected lines in stellar spectra and therefore could not be caused by rotation, which would affect all lines. Moreover, Vogel argued that equatorial speeds of over 300 km s^{-1} for some stars seemed implausible. Vogel, however, retracted his hasty objections in 1899, by which time Abney’s ideas had become generally accepted.

In 1877 Abney left Chatham for the Royal College of Science, South Kensington, where he served for 26 years. He continued his photographic researches there, and in particular explored the relationship between density and exposure in photographic emulsions, and the phenomenon of reciprocity failure in photographic photometry. He also expanded his researches into color vision, spectrophotometry, and the transmission of sunlight through the Earth’s atmosphere.

Abney’s hobbies were nature studies in the Swiss Alps, where he took regular summer holidays, and watercolor painting. From his first marriage, to Agnes Matilda Smith in 1864, he had one son and two daughters. After her death in 1888, he married Mary Louisa Meade in 1890, by whom he had another daughter.

Abney served as president of several learned societies, including the Royal Astronomical Society (1893–1895). During the years 1899–1903 he also served as principal assistant secretary to the British Board of Education. He was knighted in 1900.

John Hearnshaw

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Abubacer

➜ **Ibn Ṭufayl: Abū Bakr Muḥammad ibn ˁAbd al-Malik ibn Muḥammad ibn Muḥammad ibn Ṭufayl al-Qaysī**

Abī al-Fatḥ al-Ṣūfī

➜ **Ibn Abī al-Fatḥ al-Ṣūfī: Shams al-Dīn Abū ˁAbd Allāh Muḥammad ibn Abī al-Fatḥ al-Ṣūfī**

Abī al-Shukr

➜ **Ibn Abī al-Shukr: Muḥyī al-Milla wa-'l-Dīn Yaḥyā Abū ˁAbdallāh ibn Muḥammad ibn Abī al-Shukr al-Maghribī al-Andalusī [al Qurˁubi]**

Abū al-Ṣalt: Umayya ibn ˁAbd al-ˁAzīz ibn Abī al-Ṣalt al-Dānī al-Andalusī

Born **Denia, (Spain), *circa* 1068**
Died **Bejaïa, (Algeria), 23 October 1134**

Abū al-Ṣalt was an accomplished, though not innovative, astronomer whose most important works dealt with instruments. These were read both in the Islamic world and in Europe. He may further be considered a polymath, having also written works in medicine, philosophy, music, history, and literature.

Abū al-Ṣalt's father died while he was still a child. In Denia he studied under al-Waqqashī (1017/8–1095/6), a well-known poet, mathematician, historian, philosopher, grammarian, lexicographer, jurist, and traditionalist, who had emigrated from Toledo. Later, it seems that Abū al-Ṣalt also studied in Seville before leaving al-Andalus for Alexandria and Cairo.

Abū al-Ṣalt arrived in Alexandria, accompanied by his mother, in 1096, during the reign of the Fatimid ruler al-Mustaˁlī ibn al-Mustanṣir, in the epoch of the powerful minister al-Afḍal ibn Amīr al-Juyūsh Shāhanshāh. Al-Afḍal accepted Abū al-Ṣalt in his court immediately because of their common interest in astronomy. Around 1106/1107, Abū al-Ṣalt fell into disgrace and was imprisoned, apparently due to an incident that was recorded by Ibn Abī Uṣaybiˁa. The story goes that a ship with a cargo of copper sank near the port of Alexandria. Abū al-Ṣalt persuaded al-Afḍal that he would be able to refloat the ship; he devoted a great deal of effort and money to this objective and the ship was eventually hoisted by using intertwined silk ropes. Unfortunately, however, the ropes broke as soon as the ship started to emerge from the water; the ship sank again and nothing could be done to recover it. Al-Afḍal was furious and sent Abū al-Ṣalt to jail, where he remained in prison for 3 years and 1 month between 1107/1108 and 1111/1112. According to other versions, however, his disgrace was because of the fall of his friend and patron Mukhtār Tāj al-Maˁālī. In any case, during his stay in the jail Abū al-Ṣalt devoted himself to his writings and a great deal of his work dates from this time, mainly because he was confined to the building of the library.

On his release, Abū al-Ṣalt left Egypt and, according to some sources, went to Mahdiyya, capital of the Zīrids, on his way back to al-Andalus. He arrived in Mahdiyya in the year 1112/1113 and was welcomed by the educated king Yaḥyā ibn Tamīm al-Ṣanhājī. He settled in Mahdiyya, as a panegyrist and chronicler of the court. He devoted himself to music and pharmacopoeia, and in that city his son ˁAbd al-ˁAzīz was born. During his stay in Tunis, Abū al-Ṣalt traveled to the Sicilian court of Palermo on several occasions, apparently in his role as a physician, under the patronage of the Norman king Roger. He died, probably of dropsy, in Bejaïa on 23 October 1134. He was buried in the *Ribāṭ* of Monastir (present-day Tunisia).

Abū al-Ṣalt's works on astronomy, mathematics, music, and optics were quoted by several Hebrew authors such as Samuel of Marseille and Profiat Duran (15th century). Part of his scientific work was translated into Latin and into Hebrew. Thanks to these translations made in the Iberian Peninsula and in southern France, he became well known in Europe. Abū al-Ṣalt appears to have composed an encyclopedic work on the scientific disciplines of the quadrivium, to which some of his known treatises on these sciences would have belonged. This work was divided in four sections devoted to geometry, astronomy, arithmetic, and music, following **Aristotle**'s well-known scheme that was also used by most medieval Arabic and Hebrew authors. The title of this work, only known in its Hebrew translation, is *Sefer baHaspaqah* (probably *Kitāb al-kāfī fī al-ˁulūm* in Arabic). Several Arabic sources consider him an excellent lute player and credit him with the introduction of Andalusī music to Tunis, which eventually led to the development of the Tunisian *mālūf*. Abū al-Ṣalt was also a well-known poet and a prolific writer on history, medicine, and philosophy.

The king of Mahdiyya was particularly interested in the study of medicinal plants and was keen to discover an elixir able to transmute copper into gold and tin into silver. With this aim in mind he founded a school of alchemy, where Abū al-Ṣalt taught.

Abū al-Ṣalt's most important works on astronomy are: (1) *Risāla fī al-ˁamal bi-'l-asṭurlāb* (On the construction and use of the astrolabe); (2) *Ṣifat ˁamal ṣafīḥa jāmiˁa taqawwama bi-hā jamīˁ al-kawākib al-sabˁa* (Description of the construction and Use of a Single Plate with which the totality of the motions of the seven planets can be calculated). In this work, he describes the last, and least interesting, of the three known Andalusian equatoria, which may have been the link with the eastern Islamic instruments of this kind; however, it does seem that **Abū Jaˁfar al-Khāzin** had already described an equatorium in 10th-century Khurāsān; (3) *Kitāb al-wajīz fī ˁilm al-hay'a* (Brief treatise on cosmology); (4) a compendium of astronomy that was strongly criticized by Abū ˁAbd Allāh of Aleppo, one of the most important astronomers of the court of al-Afḍal; (5) *Ajwiba ˁan masā'il su'ila ˁan-ha fa-ajāba* or *Ajwiba ˁan masā'il fī al-kawn wa-'l-ḥabīˁa wa-'l-ḥisāb* (Solution to the questions posed, or answer to questions on cosmology, physics, and arithmetic); and, according to Ibn Khaldūn, an *Iqtiṣār* (Summary) of **Ptolemy**'s *Almagest*.

Mercè Comes

Alternate name

Albuzale

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Abū al-ˁUqūl: Abū al-ˁUqūl Muḥammad ibn Aḥmad al-Ṭabarī

Flourished **Yemen, *circa* 1300**

Abū al-ˁUqūl was the leading astronomer in Taiz, Yemen, *circa* 1300. His epithet al-Ṭabarī indicates that he or his family came originally from northern Iran. He was a contemporary of the ruler **Ashraf** and **Muḥammad ibn Abī Bakr al-Fārisī**, the latter also of Iranian stock. No details of Abū al-ˁUqūl's life are known to us beyond the fact that he was the first teacher of astronomy appointed at the Mu'ayyadiyya Madrasa in Taiz by the Sultan al-Mu'ayyad, brother and successor of al-Ashraf.

Abū al-ˁUqūl compiled an astronomical handbook (Arabic: *zīj*) for the Yemen and was not shy about admitting to having taken most of it from other sources; indeed, he called his work *al-Zīj al-mukhtār min al-azyāj* (The *Zīj* culled from other *Zīj*es). In fact, the work is based heavily on the *Ḥākimī Zīj* of the 10th-century Egyptian scholar **Ibn Yūnus**. What is original are the various tables of spherical astronomical functions for latitudes in the Yemen, and it is clear that spherical astronomy was the author's forte.

Abū al-ˁUqūl compiled the largest single medieval corpus of tables for astronomical timekeeping for a specific latitude, with over 100,000 entries. This corpus, entitled *Mir'āt al-zamān* (Mirror of Time), is computed for latitude 13° 37′, an excellent value for Taiz (accurately 13° 35′!) derived by either Abū al-ˁUqūl or al-Fārisī, and obliquity 23° 35′. In addition to tables of the hour angle and the time since sunrise for each degree of solar altitude and solar longitude, such as are found in the Cairo corpus associated with Ibn Yūnus, there are tables displaying the longitude of the ascendant or horoscopus as a function of solar altitude and longitude, and others displaying the altitude of various fixed stars at daybreak as a function of the ascendant. The inspiration for the tables associated with the ascendant seems to come from Iraq or Iran, where such tables are attested, rather than from Egypt. Abū al-ˁUqūl's extensive tables are known from a unique manuscript copied in Mocca on the Red Sea coast of Yemen in 1795. To what extent they were used over the centuries is unclear.

Abū al-ˁUqūl also prepared an almanac in which astronomical phenomena were associated with aspects of agricultural practice.

David A. King

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Abū Maˤshar Jaˤfar ibn Muḥammad ibn ˤUmar al-Balkhi

Born **Balkh, (Afghanistan), possibly 787**
Died **Wāsiṭ, (Iraq), possibly 886**

Abū Maˤshar is best known for his astrological writings; however, he also wrote on other branches of the science of the stars, including astronomical tables. There is some question about his dates of birth and death because the former is based solely on an anonymous horoscope cited in his *Book of the Revolutions of the Years of Nativities*, while the latter comes from Ibn al-Nadīm, the 10th-century bookseller. But **Bīrūnī** tells us in his *Chronology of the Ancient Nations* that Abū Maˤshar made an observation in 892, and there is a reference by Abū Maˤshar himself in the *Book of Religions and Dynasties* to stellar positions due to trepidation dated 896/897. Both would have been made when Abū Maˤshar was well over 100 if the birth date is to be believed.

Ibn al-Nadīm reports in his *Fihrist* that Abū Maˤshar was at first a scholar of *ḥadīth* (prophetic traditions), was antagonistic toward the philosophical sciences (*i. e.*, Hellenistic science and philosophy), and sought to stir popular opinion against his contemporary **Kindī**, one of the champions of these sciences. By means of a ruse, Kindī sought to interest him in arithmetic and geometry. This apparently succeeded in mollifying Abū Maˤshar; though he never became proficient in mathematics, he did become interested later in life (at age 47) in astrology, another of the Hellenistic sciences. This late start, though, did not deter him because he was said to have lived to the ripe old age of 100. Since Abū Maˤshar was considered the greatest astrologer of the ˤAbbāsid court in Baghdad, his works were prominent, and therefore he was occasionally mentioned in tales on astrology. Ibn Ṭāwūs (1193–1266) collected several anecdotes on Abū Maˤshar in his *Faraj al-mahmūm* (Biographies of Astrologers).

All works on astronomy attributed to Abū Maˤshar are lost, and only his astrological works in Arabic are known to us. Much of our knowledge of his contribution to astronomy comes to us either from other sources or by way of information gleaned from his astrological works. Abū Maˤshar's major astrological works that survive in Arabic manuscripts can be classified into three categories, based on the surviving manuscripts.

The first type is works that provide an introduction to astrology. Included in this group is Abū Maˤshar's 106-chapter work, *Kitāb al-mudkhal al-kabīr*, which he wrote "for the establishment of astrology by sufficient arguments and proofs." Not since **Ptolemy**'s *Tetrabiblos* had philosophical proofs of astrology been argued; Abū Maˤshar's philosophical basis was Aristotelian physics, which he had acquired through Kindī's circle. This work was translated into Latin in 1133 and 1140, and selections from it were translated into Greek *circa* 1000. The Latin translations had a significant influence on western European philosophers, such as **Albert The Great**. Abū Maˤshar also wrote an abridged version of his introductory work (*Kitāb mukhtaṣar al-mudkhal*), which was translated into Latin by **Adelard of Bath**.

The second type of work is Abū Maˤshar's historical astrology, which was introduced from the Sasanian tradition by al-Manṣūr, the second caliph of the ˤAbbāsid dynasty. This was part of his political strategy for laying a solid foundation for the newborn dynasty, and indeed it was used most effectively among the early ˤAbbāsids. Abū Maˤshar's monumental book on this subject, the *Kitāb al-milal wa-'l-duwal* (Book on religions and dynasties), is in eight parts in 63 chapters. The work was translated into Latin and read by **Roger Bacon**, **Pierre d'Ailly**, and Pico della Mirandola (1463–1494), and discussed in their major works. Other works in this category include *Fī dhikr ma tadullu ˤalayhi al-ashkhāṣ al-ˤulwiyya* (On the indications of the celestial objects [for terrestrial things]), *Kitāb al-dalālāt ˤalā al-ittiṣālāt wa-qirānāt al-kawākib* (Book of the indications of the planetary conjunctions...), and the *Kitāb al-ulūf* (Book of thousands), which is no longer extant but is preserved in summaries by **Sijzī**.

The third and final type is Abū Maˤshar's works on genethlialogy, the science of casting nativities. An example is *Kitāb taḥāwil sinī al-mawālīd* (Book of the revolutions of the years of nativities). The first five parts in 57 chapters (out of nine parts in 96 chapters) were translated into Greek *circa* 1000, and the Greek text was translated into Latin in the 13th century. Another work in this genre is *Kitāb mawālīd al-rijāl wa-'l-nisā'* (Book of nativities of men and women). The large number of extant manuscripts suggests its high popularity in the Islamic world.

Keiji Yamamoto

Alternate name

Albumasar

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Acyuta Piṣāraṭi

Born **Tṛkkaṇṭiyūr, (Kerala, India), 1550**
Died **(Kerala, India), 7 July 1621**

Acyuta Piṣāraṭi was a prominent figure in the annals of the medieval period. He was a versatile scholar and an original thinker who enunciated, for the first time in Indian astronomy, the correction called “reduction to the ecliptic” of the true positions of the planets. Acyuta hailed from Kerala, the narrow strip of land on the west coast of south India, and was part of a long line of astronomers who were related to each other as teacher and disciple or as father and son. Acyuta’s teacher was **Jyeṣṭhadeva,** author of the *Yuktibhāṣā*, an analytical work on mathematics and astronomy based on the *Tantrasaṅgraha* of **Nīlakaṇṭha Somayāji**.

Among Acyuta’s works on astronomy, the *Sphuṭanirṇaya* (*The Accurate Determination of the True Positions of the Planets*) is the most important. Divided into six chapters, the work shows the step-by-step reductions of the positions of the planets from their mean to true places, for an observer stationed on the Earth’s surface.

The *Rāśigolasphuṭānīti* is a shorter but highly revealing work in which Acyuta evolves a method for the astronomical procedure known as “reduction to the ecliptic” and sets out its rationale.

The *Karaṇottama* is another important work in which improved methodologies for astronomical computations are displayed, to which Acyuta has added his own commentary.

The *Uparāgakriyākrama* (*Methodology of Computing the Eclipse*) addresses both lunar and solar eclipses, while the *Uparāgaviṃśati* (*Score on Eclipses*) is a more succinct exposition of the same subject.

Another short work is the *Chāyāṣṭaka* (*Octad on the Gnomon’s Shadow*) that rationalizes the computation of the Moon’s shadow. Still another expositional work of Acyuta is his commentary in Malayalam, the language of Kerala, on an important work called the *Veṇvāroha* by the astronomer Mādhava. Acyuta’s commentary enunciates a chart for reading off the position of the Moon every 2 hours.

Besides writing works on astronomy and grammar (notably the *Praveśaka*), Acyuta was a master in the field of medicine (*āyurveda*), a fact revealed in an obituary verse composed by one of his pupils, the poet–grammarian Nārāyaṇa Bhaṭṭatiri.

Ke Ve Sarma

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Ādamī: Abū ʿAlī al-Ḥusayn ibn Muḥammad al-Ādamī

Flourished **Baghdad, (Iraq), *circa* 925**

Ādamī is noted for his work on instruments. Ibn al-Ādamī, presumably his son, wrote an influential astronomical handbook with tables (*zīj*) that was based on Indian sources. The father is mentioned in Ibn al-Nadīm’s *Fihrist* (dating from the 10th century), where he is called al-Ādamī. Because of the similarity in names, the two have often been confused in modern sources.

According to the *Fihrist*, Ādamī is the author of a work on sundials, and indeed there is an extant Paris manuscript by him that deals with vertical sundials and contains universal auxiliary tables that are used to simplify calculations. These enabled the drawing of lines for vertical sundials inclined to the local meridian at any desired angle for any latitude. **Bīrūnī** tells us in his great work on astrolabes (the *Istīʿāb*) that Ādamī was the first person to construct a “disc of eclipses” for demonstrating solar and lunar eclipses.

The son, Ibn al-Ādamī, was famous for a *zīj* entitled *Naẓm al-ʿiqd*, which was completed after his death by his student al-Qāsim ibn Muḥammad ibn Hishām al-Madāʾinī, who published it in 949/950. This nonextant work is referred to by several later authors, including **Ibn Yūnus** (died: 1009) and **Ṣāʿid al-Andalusī** (died: 1070). From the latter we learn that Ibn al-Ādamī’s *zīj* was based on the Indian methods contained in the so-called *Sindhind*, a Sanskrit work translated into Arabic by **Fazārī**. Ṣāʿid also provides crucial evidence that the theory of variable precession (or trepidation) that became known in Europe under the name of **Thābit ibn Qurra** may instead have had its source in the *zīj* of Ibn al-Ādamī, who himself may have gotten the theory from Thābit’s grandson **Ibrahīm ibn Sinān**. Ṣāʿid also informs us that Ibn al-Ādamī was a source for the story of how Indian astronomy came to Baghdad in the early 770s by way of an ambassador to the court of Manṣūr.

F. Jamil Ragep and *Marvin Bolt*

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Adams, John Couch

Born **Lidcott near Launceston, Cornwall, England, 5 June 1819**

Died **Cambridge, England, 21 January 1892**

John Adams is best remembered for his calculations concerning the location and discovery of Neptune. Born a farmer’s son, Adams showed a precocious mathematical talent and sat for the entrance at

Saint John's College, Cambridge, in 1839, winning a sizarship that partially paid his college expenses. He later married Eliza Bruce.

In July 1841, by the end of his first year, Adams began plans to investigate the irregular motions of Uranus to see if they would point to some undiscovered planet. In 1843, he finished as senior wrangler and the first Smith's prizeman, the top mathematician of his year.

By October 1843, Adams had reached a preliminary solution to the Uranus problem. In February 1844, **James Challis**, director of the Cambridge Observatory, brought Adams the results of Uranus observations sent from **George Airy**, the Astronomer Royal, thereby providing Adams with the best data available. Adams became a close personal friend of Challis.

In September 1845, Challis wrote to Airy that Adams himself hoped to write to Airy concerning the undiscovered planet perturbing Uranus, but Adams did not correspond. Instead, Adams made two unannounced visits to Greenwich, presumably wishing to discuss matters personally with the Astronomer Royal, and left a brief note about his predictions. Airy replied, with a query concerning the impact on Uranus's radius vector, daily values for which had appeared in Airy's *Nautical Almanac* since 1834. Again, Adams did not reply, but following the second letter of Airy, the dated sections of Adams's notebooks show considerable endeavor to compute this parameter, which he finally did on 1 September 1846.

Not until 13 November 1846, 6 weeks after Neptune's discovery, did the public learn of Adams's predictions supposed to have been made in October 1845. At that presentation, both Airy and Challis produced undated scraps of paper with elements of the predicted new planet written out in Adams's hand; both averred they had been given these the previous year. But neither had declared having in their possession these remarkable British predictions upon **Urbain Le Verrier**'s prediction being published in June, nor upon the new planet being found in September.

Once the new planet was found, Adams utilized the results of Challis's sky search to ascertain Neptune's true distance, eccentricity, and inclination to the ecliptic and published them at once, belying the traditional image of Adams as modest and reluctant over writing letters. He and Challis proposed the name "Oceanus" for the new planet. In recognition for his work on Neptune, the Royal Society awarded him the Copley Medal, its highest prize, in 1848.

In 1851, Adams became president of the Royal Astronomical Society and shortly after began his work on lunar theory. In 1852, he published new and accurate tables of the Moon's parallax, correcting the theory of **Philippe de Pontécoulant**. The following year saw his memoir on the secular acceleration of the Moon's mean motion, which halved the value in **Pierre de Laplace**'s incorrect solution.

In 1859, Adams became Lowndean Professor of Astronomy and Geometry at Cambridge University, succeeding George Peacock, and in 1861, director of the Cambridge Observatory, succeeding Challis. Adams demonstrated how the brilliant Leonid meteor shower of 1866 derived from an elliptical orbit being perturbed by the giant planets. He worked on cataloguing **Isaac Newton**'s unpublished mathematical writings after they were presented to the university in 1872 by Lord Portsmouth.

In 1847, Adams was offered a knighthood, but he refused it. In 1848, Cambridge University founded the Adams Prize in mathematics, physics, and astronomy in recognition of his efforts leading to Neptune's discovery. He received honorary degrees from Oxford University, Cambridge University, and other universities. He served as president of the Royal Astronomical Society from 1851 to 1853 and from 1874 to 1876. In 1866, the Royal Society awarded a Gold Medal to Adams for his lunar theory. In 1895, a portrait of Adams was engraved beside the grave of Newton in Westminster Abbey.

Many of Adams's personal papers are at Saint John's College Archives, Cambridge, and are transcribed in the McAlister collection there. Other papers are in Truro, England. Many of the crucial papers relating to the role of Adams and others about the discovery of Neptune disappeared in the 1960s and were returned to Cambridge University in 1999.

Nicholas Kollerstrom

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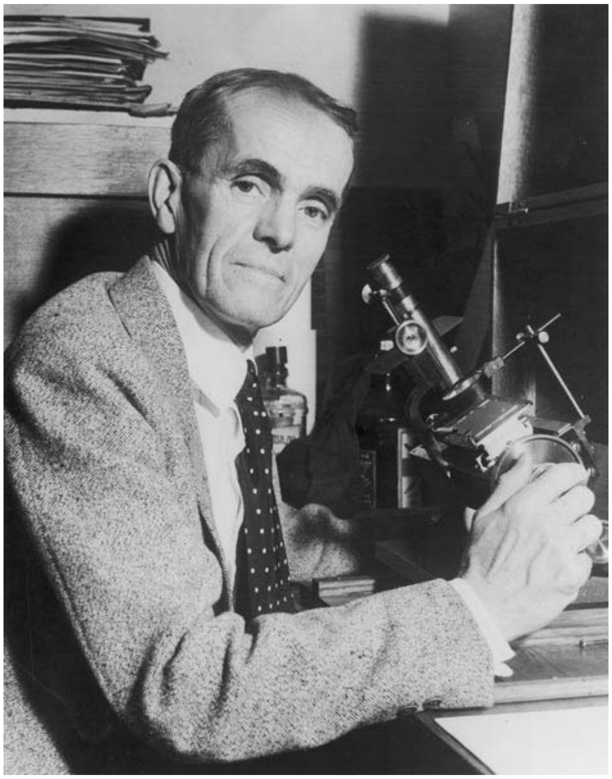
Adams, Walter Sydney

Born **Kessab, (Syria), 20 December 1876**
Died **Pasadena, California, USA, 11 May 1956**

Walter Adams directed the greatest observatory on the Earth for a quarter of a century, supervising a staff that included productive astronomers such as **Walter Baade**, **Harold Babcock**, **Edwin Hubble**, **Milton Humason**, **Alfred Joy**, **Paul Merrill**, **Rudolph Minkowski**, **Seth Nicholson**, **Frederick Seares**, and **Olin Wilson**, while devoting most of his time to research. He codiscovered the method of determining a star's luminosity from its spectrum and contributed significantly to the design and construction of three successive world's largest telescopes – the 60- and 100-in. at Mount Wilson and the 200-in. Hale telescope on Palomar Mountain, both in California.

His New England-born, college-educated parents, Lucien Harper Adams and Dora Francis Adams, were serving as Congregational missionaries in the Middle East. Home-schooled, Adams was far ahead in Greek and Roman history and theology but rather ignorant of his own country when he first entered an American school at the age of eight. At Dartmouth College he noted that he had a strong preference for



exact subjects with definite answers as compared with those involving alternatives and the exercise of considerable judgment.

When he took the astronomy course at Dartmouth, Adams found that his professor, **Edwin Frost**, was an admirable teacher who gave the subject a strong appeal both on the mathematical and the physical side. In 1898, when Adams completed his AB, **George Hale** hired Frost as one of the first professors of astrophysics at the new University of Chicago. Adams went along as one of Frost's first graduate students. Adams reported that his employment as an astronomer was an interesting illustration of the effect of relatively small events on the course of individual lives in which a very slight change in circumstances might equally well have led him to follow the teaching of Greek as a profession.

After 2 years of studying at Chicago and apprenticing at its Yerkes Observatory, in 1901 Adams went to Munich with the intention of earning a Ph.D. under **Hugo von Seeliger** and **Karl Schwarzschild**. However, Hale, whom Adams idolized, called him back to Yerkes after a year. Adams remained an associate of Hale for the remainder of the latter's life.

Adams became an expert spectroscopist, and when Hale went to Pasadena in 1904 to establish what would become the Mount Wilson Observatory of the Carnegie Institution of Washington, Adams went along as his right-hand man. Adams served as acting director during Hale's many illnesses and as director from 1923 to 1945.

Adams worked with Frost and others on radial velocities of stars at Yerkes, but in the early years at Mount Wilson he joined Hale in solar investigations. Adams showed that the Sun's equatorial regions rotate in about 25 days, while near the poles the period is almost 34 days. Using large spectrographs with the horizontal Snow telescope and later with the 60-ft tower telescope that Hale had built, the group obtained high-dispersion spectra of sunspots as well as interspot regions. Adams helped measure some 11,000 spectral lines and showed that the lines enhanced in sunspots were precisely those that were stronger in the cooler parts of a laboratory flame. Some lines in the sunspot spectrum are from neutral atoms, which survive at cooler temperatures, while others in surrounding areas are from ions, which are more abundant at higher temperature. Thus it was shown that sunspots are cooler than their surroundings.

This work led directly to Adams's greatest achievement. Starting in 1914, Adams and a German visitor to Mount Wilson, **Arnold Kohlschütter**, found that some spectral lines are stronger in luminous stars (giants) while other lines are stronger in stars that are intrinsically dimmer (main sequence stars). Calibrating the measurements with a few stars close enough to have their distances measured directly by trigonometric parallax, Adams and Kohlschütter showed that the ratios of certain spectral lines, especially those from ionized atoms, depended on the luminosities of the stars (via a dependence on the densities of the atmospheric gas, lower in the brighter stars). This allowed stellar distances to be determined with the spectrograph, a procedure now known as spectroscopic parallax. By 1935, when Adams, Joy, Humason, and Ada M. Brayton published their monumental *Spectroscopic Absolute Magnitudes and Distances of 4179 Stars*, the number of stars of known distance was increased one hundred-fold.

It was Adams who discovered, in 1914, that 40 Eridani B (also designated 2 O Eridani B) and Sirius B were low-luminosity stars of spectral class A. **Arthur Eddington** pointed out a decade later that these stars, now known as white dwarf stars, must be stars of extraordinary density. In 1925, following Eddington's suggestion that the gravitational redshift predicted by **Albert Einstein**'s General Theory of Relativity might be observable in these stars, Adams attempted the measurement, finding almost exactly the expected value. After later work showed that the real redshift was even larger (because the star was even more dense than Eddington had supposed), Adams was criticized. However, it became clear still later that he had measured a mix of light from Sirius A and B, so that his measurement was a honest one, but wrong for Sirius B.

Adams collaborated with other Mount Wilson spectroscopists, especially Joy, and he shared data with many others. **Theodore Dunham Jr.** recalled that they were working on stars one night when Adams suggested that they take a shot at the infrared spectrum of Venus, which was easily observable at the time. Using new infrared-sensitive plates developed at Eastman Kodak, they found some extraordinary band structure. The bands, which had not yet been seen on Earth, turned out to be due to carbon dioxide, as Dunham proved empirically by filling a 70-ft.-long pipe with the gas and obtaining the same spectrum, and for which **Arthur Adel** soon provided the theoretical basis. It was the first indication that Venus has an enormous amount of carbon dioxide in its atmosphere.

For years Mount Wilson had the world's only Coudé spectrograph, and the staff took full advantage of its high dispersion. Between 1939 and 1941, Adams and Dunham discovered several absorption lines produced in interstellar gas clouds, including some produced by molecules of CN and CH, the first molecules detected in interstellar space. By 1949, Adams had used very high dispersion to show that there are lines produced by several different clouds along the line of sight to some stars.

Harlow Shapley recalled that:

> Adams strove to excel in everything he undertook – in endurance at the business end of a telescope, in quality of spectrum plates, in hiking

speed up the mountain trail from Sierra Madre, in tennis, golf, billiards, bridge – and he did excel. But I never heard him call attention to his excellence. I remember complimenting him once on his designing the series of powerful and tricky spectrographs that were used in the Mount Wilson stellar and solar work. "It is a very low form of cunning" he replied (Shapley, 1956).

Adams was proud to be related to two US presidents, and many of his traits were attributed to his New England heritage. These qualities included his reserve and his legendary frugality. He used 25-W light bulbs in the domes and insisted that observers could take no more than two slices of bread, two eggs, and coffee for the midnight meal. Adams raised salaries only when absolutely necessary, and often returned part of his budget to the Carnegie Institution. When he asked to be allowed to spend a bit to obtain or retain the services of an outstanding astronomer like Baade, he usually offered to find the necessary funds in his own budget.

As director, Adams quietly led by example, preserving the dignity and eminence of the observatory he had inherited from Hale. He hired excellent men, and he helped enormously in the design and construction of Caltech's 200-in. Hale telescope on Palomar Mountain. He spent his retirement years at the Hale Solar Observatory in Pasadena, where he reduced data from previous observations.

Adams married Lillian Wickham in 1910. She died in 1920, and in 1922 he married Adeline L. Miller, with whom he had two sons. Adams was awarded the Gold Medal of the Royal Astronomical Society in 1917, the Henry Draper Medal of the National Academy of Sciences in 1918, the Janssen Prize of the French Astronomical Society in 1926, the Catherine Wolfe Bruce Gold Medal of the Astronomical Society of the Pacific in 1928, the Janssen Medal of the French Academy of Sciences in 1935, and the Henry Norris Russell Lectureship of the American Astronomical Society in 1947. Although he never completed graduate training, Adams was awarded honorary Ph.D., Sc.D., or LLD degrees by seven universities and colleges.

Joseph S. Tenn

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Adel, Arthur

Born **Brooklyn, New York, USA, 22 November 1908**
Died **Flagstaff, Arizona, USA, 13 September 1994**

Arthur Adel was a pioneer in the identification of specific molecules in planetary atmospheres through his studies of planetary infrared spectra, through his fundamental experimental measurements of molecular and gas mixture spectra, and through observational studies of the Earth's atmosphere. He was born to immigrant orthodox Jewish parents, Morris Adel from Russia and Jennie (*née* Schrieber) from Poland. The family relocated to Detroit, Michigan, where Adel received the majority of his precollegiate education while working part-time in a variety of jobs. While in high school, Adel was uncertain of his future career path and took an extended curriculum of practical machine shop and other mechanical arts courses in addition to all the science and mathematics courses available. The mechanical skills thus acquired helped him pay for his college education and later proved of substantial benefit in his experimental scientific work.

After a year of full-time work as a machinist, Adel entered the University of Michigan at Ann Arbor. He graduated with a double undergraduate major in mathematics and physics in 1931. Working with Michigan physicists David M. Dennison, Earnest F. Barker, and Harrison M. Randall, all leading authorities in the rapidly emerging field of infrared spectroscopy, Adel earned his Ph.D. in 1933 with a theoretical dissertation on the infrared spectrum and structure of the carbon dioxide molecule. His work on carbon dioxide proved astronomically timely. Using the energy level diagram he had computed for carbon dioxide, Adel identified the exact vibrational and rotational transitions that were observed experimentally, and in the spectrum of the planet Venus, by **Walter Adams** and **Theodore Dunham,** at Mount Wilson Observatory. Thus, Adel was able to confirm their tentative identification of carbon dioxide in the Venusian atmosphere with data in his dissertation.

As a result of an initiative by Lowell Observatory trustee Roger Lowell Putnam, Adel was offered employment at Lowell Observatory after completing his Ph.D. In the previous decades, **Carl Lampland**, Lowell Observatory, had been working with **William Coblentz** of the National Bureau of Standards on various spectroscopic projects, but these studies had produced little in the way of published results. Putnam's intent was to reinvigorate astrophysical research at Lowell Observatory, initially using observational work that had been completed but not appropriately interpreted or published by the observatory staff. Adel worked in facilities provided by the University of Michigan under agreement with Lowell Observatory as well as at the Flagstaff, Arizona, observatory. In 1933 and 1934, he analyzed spectra of the major planets (Jupiter, Saturn, Uranus, and Neptune) that had been obtained by observatory director **Vesto Slipher**. Adel showed that the bands in the spectra of the major planets, which **Rupert Wildt** had previously attributed to methane and ammonia, were, indeed, harmonics of the fundamental vibrations of methane and ammonia molecules. Adel's proof involved not only the theoretical calculation of all possible harmonics of the fundamental vibrations of these molecules, but also the photography of those spectra. Working at pressures up to 40 atm through 45-m path lengths, Adel photographed the spectra of methane, ammonia, and various mixtures of the two molecules as a function of pressure in the long-path-length tubes to simulate various depths in the planetary atmospheres. Adel's work involved not only the identification of these bands but also the calibration of their strengths as a function of pressure. **Henry Norris Russell** later commented that Adel's proof was "… as beautiful an application of spectroscopic theory as one could desire to see." During this period of work for the Lowell Observatory, Adel also revised **Samuel Langley**'s incorrect infrared wavelength scale, and recorded both the prismatic (low-resolution) and the grating (high-resolution) combined spectra of the Sun's and the Earth's atmosphere, known as the solar-telluric spectrum.

After completing 2 years of work on the Lowell Observatory projects, Adel accepted a postdoctoral fellowship at Johns Hopkins University. Before leaving Ann Arbor for Baltimore, Maryland, Adel married Catherine Emilia Backus, who at the time was studying mathematics and French at the University of Michigan. They had no children.

At Johns Hopkins University, Adel was employed by physicist Gerhard Dieke working on the atomic spectrum of hydrogen; he also taught astronomy in an evening class. More importantly, however, Adel also established strong working relationships with Johns Hopkins's distinguished infrared spectroscopists **Alfred Pfund** and **Robert Wood**. Adel learned valuable experimental skills from Pfund including the techniques for preparing sintered selenium-on-glass filters that passed infrared radiation but blocked scattered radiation in other wavelengths for improved signal-to-noise ratios.

In 1936 Adel returned to the Lowell Observatory, where the high and dry climate was ideal for his study of water vapor in the Earth's atmosphere. As part of his continued work on the solar-telluric spectrum, he corrected the spectrum of ozone, and discovered the presence of nitrous oxide and deuterium hydroxide in the Earth's atmosphere. At the suggestion of **Charles Abbott** of the Smithsonian Institution, and using a potassium bromide prism provided by Abbott, Adel discovered what is now called the 20-μm window in the Earth's atmosphere. This transparent region in which there is no water absorption, from 16 μm to 24 μm, has since proved vital for astronomical studies in the infrared. Adel's prismatic spectrum of the infrared emissions from the Moon proved for the first time that it radiated as a black body.

Adel's work at Lowell Observatory was interrupted in 1942 by the advent of World War II. After a brief stint in Washington, DC, during which he was involved in degaussing submarines, Adel returned to the University of Michigan, where he taught physics to meteorologists while conducting infrared research. Adel's most important contribution to the war effort was his demonstration that a critical radar system design was flawed. Using exceptionally high resolution, which he achieved with a finely tuned grating spectrometer, Adel showed that the radar frequency chosen coincided nearly exactly with a very narrow band in the infrared spectrum of water, which absorbed and completely masked the radar signal.

In 1946, **Gerard Kuiper** offered Adel a position on the staff of the McDonald Observatory. Kuiper's intent was to use the 82-in. telescope and spectrograph to extend spectral studies of the planets. However, living conditions in Fort Davis, Texas, were not attractive, and the Adels returned immediately to Michigan. **Robert McMath** offered Adel a position on the staff of the McMath–Hulbert Solar Observatory [MHSO] at Lake Angelus, Michigan. Adel's assignment at MHSO was initially to study solar flares and prominences in hydrogen alpha light, a project which made little use of Adel's real experimental strengths. Soon, however, the observatory received a grant from the United States Air Force to study ozone levels in the Earth's atmosphere. The work was to be carried out at Holloman Air Force Base in New Mexico and was assigned to Adel. At Holloman, Adel designed and supervised the construction of an observatory in a remote part of the base from which atmospheric studies were conducted. He developed a simple method for determining the effective radiation temperature of the ozone layer from ground level. In addition, Adel extended his solar-telluric studies to the near-infrared spectrum using the high-resolution capabilities made possible by the Cashman lead sulfide detector.

In 1948, with the Air Force work completed, the Adels moved back to Flagstaff, where he became a professor of physics at Arizona State College [ASC] (now Northern Arizona University) and spent the remainder of his life. Using the funds provided by the Air Force, Adel built the Atmospheric Research Observatory at Arizona State. The observatory was equipped with the first telescope ever designed specifically for use in the infrared, a 24-in. reflector built by J. W. Fecker Company. Using that telescope and its associated spectrograph, Adel continued to study the vertical atmospheric distribution of ozone. His revised technique, based on both ultraviolet and infrared measurements, not only contributed to improved understanding of the variations in ozone levels, but also identified previously unknown periodic fluctuations in the Earth's upper atmosphere that have since been confirmed using other techniques.

Roy H. Garstang

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Adelard of Bath

Born **probably Bath, England, *circa* 1080**
Died ***circa* 1152**

Adelard of Bath, Arabic scholar and humanist, was a pioneer in introducing Arabic science into the Latin curriculum of the liberal arts.

Originally from Bath in the west of England, Adelard went abroad to study – first to France, and then, probably following in the wake of the First Crusade, to the Principality of Antioch, and to Magna Graecia (southern Italy) and Sicily. After 7 years of absence he returned to England, probably spending most of his time in Bath, but during the troubled years of the civil war (1135–1154) he may have joined the household of the Duke of Normandy, since he dedicated his last work, *De opere astrolapsus*, to Henry, the son of the duke, and the future King Henry II. His works were well known both in northern France (*e. g.*, at Mont-St-Michel and Chartres) and in England, where several students and followers of his can be identified.

Adelard regarded "philosophy" (the seven liberal arts that were the backbone of education in the secular arts since late Antiquity) as a whole, whose parts could not be studied without one another. He aimed to show this in an exhortation to the study of philosophy, which he called *De eodem et diverso* (On the same and the different), and we have notes by him on music, and evidence that he wrote a text on rhetoric. Nevertheless, it is to geometry and astronomy that Adelard paid most attention. He made the first complete translation (from Arabic) of Euclid's *Elements*, and his adaptation of this version for teaching (the so called Adelard II Version) became the standard textbook used for teaching geometry for several generations of students. In astronomy, Adelard translated a set of astronomical tables by **al-Khwarizmi**, together with the rules for using them. The starting point of the tables is 1126, and one of the half-dozen extant manuscripts preserves a copy made in the scriptorium of Worcester Cathedral before 1140. They follow the Indian models of computation that had been used by early generations of astronomers of the Abbasid Period in Baghdad, but which had been superseded by Ptolemaic models in the Islamic Orient by Adelard's time.

Drawing on his translation of the *Elements* and on the *Tables*, as well as on earlier texts on the instrument, Adelard wrote an original work on the astrolabe: *De opere astrolapsus* (1150). Aside from giving instructions on how to use the astrolabe, this work provides an account of Ptolemaic cosmology. Adelard regarded the ultimate aim of astronomy as enabling one "not only to declare the present condition of earthly things, but also their past or future conditions" (*De eodem et diverso*, p. 69), and to further this aim he translated two Arabic texts on astrology: The *Abbreviation of the Introduction to Astrology* of **Abu Ma'shar**, and the *Hundred Aphorisms* attributed to **Ptolemy**, as well as, apparently, comparing the doctrines of Arabic astrology with those of the Latin textbook of Firmicus Maternus. Another application of astronomy was magic, to which Adelard contributed by translating a text on the manufacture of talismans by **Thabit ibn Qurra**.

Through his translations of Euclid's *Elements* and the *Tables* of al-Khwarizmi, Adelard considerably expanded the range of the traditional seven liberal arts. (Both texts were included in the well-known two-volume "Library of the Liberal Arts"—the *Heptateuchon* of Thierry of Chartres of the early 1140s.) However, he also ventured outside this curriculum by introducing (avowedly as a result of his "Arabic studies"—*studia Arabica*) the science of nature, or physics, in the form of a series of questions concerning topics arranged in ascending order, from the seeds within the Earth to the highermost heaven (his *Quaestiones naturales*). The physical questions concerning the heavenly bodies include "Why is the Moon deprived of light?," "Why do the planets not move with a constant motion?," "Why do the planets move in the opposite direction from the fixed stars?," "Why do stars appear to fall from the sky?," and "Are the heavenly bodies animate?"

Adelard's influence on the teaching of geometry in Western Europe was much greater than on that of astronomy, since the *Tables* of al-Khwarizmi were soon eclipsed by those of Toledo, and other texts on the astrolabe and astrology issuing especially from Toledo proved more popular than his own. However, the popularity of the *Quaestiones naturales* ensured that his discussions of cosmology were well known, and at least one English scholar, Daniel of Morley (flourished 1175), knew the cosmological section of the *De opere astrolapsus*, which he quotes in his own cosmology, the *Philosophia*.

Charles Burnett

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Adhémar, Joseph-Alphonse

Born **Paris, France, February 1797**
Died **Paris, France, 1862**

In 1842, French mathematician Joseph Adhémar proposed that changes in the Earth's orbital elements could affect long-term climate causing the "ice ages."

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Aegidius Romanus

➜ **Giles of Rome**

Aegidius Colonna [Columna]

➜ **Giles of Rome**

Aeschylus

Flourished **late 5th century BCE**

Not to be confused with the Greek dramatist, Aeschylus (with his teacher **Hippocrates**) concluded that a comet's tail is not part of the cometary body itself; rather it is merely sunlight reflected from atmospheric moisture attracted by the comet.

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Agecio Tadeá

➜ **Hájek z Hájku, Tadeá**

Aḥmad Mukhtār: Ghāzī Aḥmad Mukhtār Pasha

Born **Bursa, (Turkey), 1839**
Died **Istanbul, (Turkey), 21 January 1919**

Aḥmad Mukhtār was a soldier and a statesman (rising to the rank of Turkish general and receiving the title "Ghāzī" or warrior) who also wrote many works in the fields of mathematics and astronomy. He is known especially for his studies on reforming the Islamic calendar as well as the making and use of astronomical instruments.

Aḥmad Mukhtār stemmed from a family prominent in the silk trade; after the death of his father, he was educated in various military schools, and the military became his lifelong career. Aḥmad Mukhtār established close ties with the Ottoman court, which led to his tutoring Prince Yūsuf ʿIzz al-Dīn (1865) and accompanying Sultan ʿAbd al-ʿAzīz to Europe in 1867. He served the state for 55 years and rose to high rank, becoming president of the Senate in 1911 and Grand Vizier for a brief period in 1912. Aḥmad Mukhtār remained in the Senate until 1918 just before his death. Because of his military success, he was granted numerous titles, including Ghāzī and Pasha.

Aḥmad Mukhtār contributed much to the field of astronomy, especially with regard to reforming the Islamic (*hijra*) calendar. When he was in Egypt between 1882 and 1908 as Ottoman High Commissioner, he wrote his *Iṣlāḥ al-Taqwīm* (written in both Turkish and Arabic) that dealt with the fiscal problems caused by the discrepancies between the *Hijra* and Gregorian calendars. Aḥmad Mukhtār advocated a uniform *Hijra* solar (*Shamsī*) year for all Muslims. In accordance with his new calendar system, the work contains a tabulation of conversions between lunar-*hijra*, Gregorian, and solar-*hijra* New Year's days until 2212. The work was also translated into French. Other works dealing with the calendar include *Taqwīm al-sinīn*, which lists in tabulated form the daily equivalents between the lunar and Gregorian calendars, covering the *hijra* years 1256 to 1350 (*circa* 1840–1931), and *Taqwīm-i sāl*, which provides general information about the calendar in the Ottoman Empire. He also wrote other works dealing with calendars, some of which are in Arabic.

Another astronomical work, entitled *Rīyāḍ al-mukhtār mir'āt al-mīqāt wa-'l-adwār*, deals with timekeeping. Written in Istanbul, the work contains information on instruments and their categorization. Other subjects include measurement of time, information about latitude and longitude, and an evaluation of calendars. *Majmūʿah-i ashkāl* is a supplement at the end of the book containing figures and tables. Aḥmad Mukhtār also wrote a work on the definition and use of an astronomical instrument called *al-Basīṭa*.

Finally, another important work of Mukhtār Pasha should be mentioned here. Entitled *Sarā'ir al-Qur'ān fī taqwīn wa-ifnā' wa-Iʿādat al-akwān* and published in Istanbul in 1917, it was written in order to reconcile religious issues with scientific discoveries and discusses how to reconcile Qur'ānic verses with the latest developments in science. This work was one of the first during the modern period to address these issues and was later translated into Arabic from Turkish.

Salim Aydüz

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Ainslie, Maurice Anderson

Born **Corfe, Somerset, England, 4 October 1869**
Died **Wallisdown, Dorset, England, 19 January 1951**

Maurice Ainslie, an archetypical English amateur astronomer, was particularly involved with telescope design and with observing planets (mainly Jupiter and Saturn). As a contributor to journals and as a radio broadcaster, he was active in promoting astronomy to the general public. A Royal Navy officer by profession, he was a leading member of the British Astronomical Association for many years.

Ainslie was the youngest son of Reverend Alexander Colvin Ainslie and Catherine Susan Sadler. His father was an Archdeacon (senior priest) in the Church of England. He grew up mainly in the rural county of Somerset in the west of England.

From 1884 to 1888 Ainslie attended Marlborough College, a school specializing in the education of sons of clergymen. He became interested in astronomy at Marlborough College, joining the Astronomical Section of the school's Natural History Society. Ainslie gave several talks to the section, covering topics such as the constellations, the planets, and the telescopes (an interest he would hold for the rest of his life). The Astronomical Section enjoyed using a 4-in. Cooke refracting telescope that belonged to the college, and it was with that telescope that he took some photographs of the Moon during the Christmas holidays of 1886.

Ainslie was accepted by Gonville & Caius College in the University of Cambridge. At Cambridge he was able to observe with the 11.5-in. Northumberland Telescope. **John Adams**, famous for his prediction of Neptune, was the director of the Cambridge Observatory at that time. Ainslie graduated in 1891 with a BA degree in mathematics and natural sciences.

The next 2 or 3 years must have been a difficult time for Ainslie. He had decided to become a teacher, but it seems that the career did not suit him. He had two short-lived positions as a schoolmaster, first at Derby School and then at Giggleswick, before joining the Instructional Branch of the Royal Navy in 1894.

At that time the Royal Navy was the largest navy in the world. It operated on a worldwide scale and possessed a fine tradition of assisting scientific research and exploration. Furthermore, practical navigation depended very much on astronomical observations and knowledge in that era. Ainslie served with the Royal Navy in the Mediterranean, the Channel, and at various shore establishments including the Royal Naval College at Greenwich.

Shortly after joining the Royal Navy, Ainslie built a telescope for himself. It was a 9-in. reflector set on an altazimuth mount and utilized a mirror he had ground himself. Ainslie retained an interest in all aspects of practical optics for the remainder of his life.

Ainslie was closely involved in the activities of the British Astronomical Association [BAA], which was founded in 1890. He contributed numerous short reports to the *Journal* of the BAA on various topics. Ainslie served as director of the Methods of Observation Section from 1917 to 1932. The Methods of Observation Section would perhaps today be called the "Equipment Section," as it was concerned with the exchange of information on all items of equipment from lenses to mountings. Ainslie also served as director of the Saturn Section for 6 years.

Ainslie was a regular contributor to BAA meetings, offering advice and information from his long experience as an amateur observer. Saturn and Jupiter were the principal objects of Ainslie's observations. He was fortunate to observe a rare event when the ring system of Saturn occulted the star BD +21° 1714 on 9 February 1917. He made a full report of this event in the BAA *Journal*. On the night of 29/30 December 1918 Ainslie was able to observe a complete rotation of Jupiter, making a particular study of the equatorial regions. (On one occasion he related how he observed the Green Flash twice on the same day from the rolling deck of *HMS Roxburgh* in the Bay of Biscay.) Ainslie was elected president of the BAA from 1928 to 1930.

Ainslie had many other scientific interests outside of astronomy. He was an expert in the optics of the microscope and contributed articles on this subject to the *English Mechanic*. He was the president of the Photomicrographic Society in 1920. He also was keenly interested in radio, experimenting with early crystal and valve circuits. Ainslie arranged for experimental Greenwich Mean Time [GMT] time signals to be broadcast from the Eiffel Tower in Paris in 1921. He advocated this as a method of providing amateur astronomers with an accurate time standard. In common with his activity in the BAA, Ainslie was closely involved with the radio amateur fraternity, serving on the council of the Radio Society of Great Britain.

Ainslie retired from naval service in 1922 with the rank of instructor captain. In his active years of retirement Ainslie was involved with the Bournemouth Natural Science Society, a local group dedicated to self-education in the sciences. Despite suffering from arthritis, Ainslie continued to be involved with his many scientific interests. He gave not only gave astronomical lectures but also popular talks on the radio. Poor health forced him to resign as director of the BAA Saturn Section in 1946.

Mark Hurn

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Airy, George Biddell

Born **Alnwick, Northumberland, England, 27 July 1801**
Died **Greenwich, England, 2 January 1892**

George Airy was the seventh Astronomer Royal; he made major and lasting contributions to many branches of astronomical and physical science and engineering, and his procedures for the mathematical treatment of observations remained the standard for more than a century. His name is associated (Airy diffraction pattern) with the appearance of light that has passed through a small circular aperture.

The son of farmer William Airy and Ann Biddell, Airy was schooled locally at Colchester. At age 12, he asked his uncle, Arthur Biddell, to take him in; his uncle raised him from that point. At school Airy excelled in classics, history, and mathematics. He taught himself a wide range of other subjects, including astronomy, chemistry,

and navigation. Airy entered Trinity College, Cambridge, in 1819, and graduated as senior wrangler in 1823. He contributed several papers, mainly on optical subjects, to the Cambridge Philosophical Society. A noteworthy example was "On a peculiar defect in the eye, and a mode of correcting it." Airy was myopic, and wore the usual concave spectacles for this, but his left eye remained almost useless; he discovered by experiment that the eye was seriously astigmatic, and designed a concavo-cylindrical lens to correct it. His solution is routinely prescribed today.

Airy became a fellow of Trinity College in 1824, and Lucasian Professor of Mathematics in 1826. Two years later he was appointed Plumian Professor of Astronomy, which included superintendence of the newly created Cambridge University Observatory. Airy devised a new system for the reduction of the positional observations, and was also responsible for the design and erection of the Northumberland 11¾-in. refractor, in a double-yoke equatorial mounting that he developed from a form previously used only for small instruments. Still in use today, the mounting proved to be extremely successful and was the forerunner of those used for great telescopes at the Mount Wilson Observatory and Palomar Observatory.

Meanwhile, Airy continued his research into the wave theory of light and many other topics. His contributions in such diverse fields as optical diffraction and engineering metrology, for instance, are remembered by the continued use of the terms Airy disk and Airy points. At the second meeting of the British Association for the Advancement of Science in 1832, Airy was invited to present a report on the Progress of Astronomy, which was to prove to be of seminal importance. He arranged for the reduction and publication of **Stephen Groombridge**'s *Catalogue of Circumpolar Stars* when Groombridge himself was incapacitated by a stroke, thus salvaging an invaluable reference source. Having directed the Cambridge Observatory so successfully, it was inevitable that Airy should succeed Astronomer Royal **John Pond** when the latter retired in 1835.

Airy directed the Royal Observatory for 46 years, and reorganized the establishment so effectively that it continued to be run on the pattern he formulated for more than 120 years. He introduced full reduction and annual publication of all the observations, and also organized the reduction and publication in three massive volumes of all the positional observations of the Sun, the Moon, and the planets that had been made at Greenwich between 1750 and 1830. In addition to maintaining and developing its traditional role in positional astronomy and time determination, Airy introduced regular photography of the Sun's surface, stellar radial-velocity measurements, and systematic monitoring of the Earth's magnetism. He also designed the great equatorial telescope, a 12¾-in. refractor in a mounting developed from his design for the Northumberland telescope.

Arguably, Airy's greatest achievement at Greenwich was the design of a new suite of instruments to meet the increasing standards of accuracy required for positional astronomy: The altazimuth, the reflex zenith tube, the barrel chronograph, and, most notably, the transit circle. These instruments, introduced between 1847 and 1854, were to prove the best in the world at the time and to have a combined working life of 313 years; they also provided the design basis for major positional instruments for generations to come. Airy retired on 15 August 1881 and moved to a house nearby.

Airy's transit circle – described by **Simon Newcomb** as "the most serviceable meridian instrument ever constructed" – commenced work in 1851; its last observations were made in 1954, and were reduced using Airy's procedures. At the Washington Conference of 1884, the longitude of the Airy transit circle had been adopted as the prime meridian and the reference for the world's time zones.

Airy undertook many nonastronomical tasks: He served on the Board of Longitude and more than 30 Royal Commissions and government Select Committees, and was the *de facto* chief scientific advisor to the governments of his day. Airy chaired the committee to restore the national standards of length and weight following their destruction in a fire at the Houses of Parliament, and played a leading role in the introduction of the electric telegraph and the distribution of time signals, the standardization of railway gauges, and the correction of magnetic compass disturbances in iron ships. He also participated in numerous international collaborations, including the Greenwich–Paris and the Pulkovo–Greenwich–Valencia longitude determinations, and organized expeditions to observe several solar eclipses and two transits of Venus. Airy was asked to draw up detailed instructions for the determination of the Canada–United States boundary, and trained the officers concerned for several weeks at Greenwich. He gave similar assistance to the establishment of the Oregon state boundary.

Airy published a dozen books, mainly in the fields of mathematics, optics, and astronomy, and wrote over 500 scientific papers. He also wrote essays on topics ranging from early Hebrew scriptures to Roman military history. One of his most successful books was *Six Lectures on Astronomy* (London, 1849), based on a course of public lectures given on the occasion of the opening of the Ipswich Museum. Twelve further editions of this work, later retitled *Popular Astronomy*, appeared for over 40 years.

Airy served as president of the Royal Society of London during 1871–1873, and was awarded both its Copley Medal and its Royal Medal (twice). He was a member of the Council of the Royal Astronomical Society continuously from 1830 to 1886, during which time he served as the president for four terms. Airy received a knighthood in 1872, and in 1875 became the first scientist to be appointed a freeman of the City of London. He was also honored by several universities and numerous overseas academies.

In character Airy was very industrious and energetic, had total self-confidence, and possessed a strong sense of duty and moral rectitude. He was famously meticulous and carefully preserved all documents and correspondence, even inventing a filing system for the purpose. His sense of order has proved of great benefit to posterity, establishing an archive that is remarkable in its value and completeness. Airy's own high standards led him to expect much of others, but though demanding of his staff he was also very fair. For much of the 20th century, however, it was fashionable to denigrate him as a tyrannical employer, but these criticisms were greatly exaggerated. They largely arose from the statements of a young assistant, serving under Airy only briefly, who later wrote disparagingly of Airy's style of management in a program that had been completed some three decades before his own birth! Recent research has shown such criticisms to be totally undeserved.

Airy has been unjustly criticized in connection with the prediction and discovery of the planet Neptune, and consequent loss of priority for the young Cambridge student **John Adams**. Searching for a hypothetical planet was not within the remit of the Royal Observatory with its extensive programs and limited resources, and Airy quite properly suggested that it could more appropriately be sought with the Northumberland refractor at Cambridge Observatory. If **James Challis**, Adams' professor at Cambridge, had not been dilatory Neptune might well have been found there. Archival evidence shows that Airy behaved entirely correctly.

Airy was a devoted family man: In 1830 he married Richarda Smith, eldest daughter of the Chaplain to the Duke of Devonshire. They had nine children; the three eldest all died young. Airy was sparing of his friendship, but remained very close to his lifelong friends, notably Sir **John Herschel**.

Gilbert E. Satterthwaite

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Aitken, Robert Grant

Born **Jackson, California, USA, 31 December 1864**
Died **Berkeley, California, USA, 29 October 1951**

Binary star astronomer Robert Aitken began to lose his hearing in early childhood. A "Record of Family Traits" filled out for the Eugenics Record Office showed that the cause of his deafness was *catarrhal otitis media* (middle-ear hearing loss). Despite a progressive type of deafness, he still was able to enjoy music somewhat, with the help of a hearing aid.

Aitken entered Williams College in Massachusetts in 1883, intending to study for the ministry. After graduating in 1887, he married and was hired by Livermore College in California. He moved on to the University of the Pacific in 1891, serving as professor of classics but also teaching some astronomy and supervising the university's modest observatory and 6-in. refractor. Correspondence with **Edward Holden**, first director of Lick Observatory, documents Aitken's gradually increasing interest in astronomy, and he was appointed to a 1-year position at Lick in 1895. Curiously, Aitken's successor at the University of the Pacific, **Heber Curtis**, also taught classics with mathematics and astronomy initially as sidelines, and also moved on to Lick Observatory. Aitken remained at Mount Hamilton the rest of his career, being promoted from assistant astronomer to astronomer in 1906. He served as associate director from 1923 to 1930 and as the fourth director, succeeding **William Campbell** in 1930 and retiring in 1935. Aitken had no immediate scientific heirs at Lick Observatory. He had brought in **Gerard Kuiper**, as a double star observer in 1933, but the next director (**William H. Wright**) preferred to make appointments in observational astrophysics, leaving Kuiper to go on to Harvard.

Communication in the world of pure research was difficult for Aitken because of his deafness. He relied primarily on speechreading (formerly called lipreading). One report about an experience at the first Astronomical Union Assembly in Rome in 1922 indicated that Aitken did not respond to a message even when it had been shouted at him. Dr. **Charles Shane**, in an unpublished autobiography, "Life of Mt. Hamilton, 1914–1920," described Aitken's voice as rather hollow and resonant, a result of a "considerable degree of deafness." At one point in his career, Aitken was nearly killed when he did not hear the approach of an automobile.

During his early years at Lick Observatory, under the direction of **Edward Barnard**, Aitken worked with the 12-in. refracting telescope, observing comets, asteroids, and other objects. He soon became fascinated with binary sars, and it is as a double-star astronomer that he is best known. His first publication focused on double-star measurements.

Its appearance, in an 1895 issue of the *Publications of the Astronomical Society of the Pacific*, led to a comprehensive survey of double stars with **William Hussey**, making many measurements on 12- and 36-in. telescopes. Hussey left the project in 1905, and Aitkin completed the survey to the 9th magnitude limit of the *Bonner Durchmvisterung*.

Aitken's discovery of over 3,000 double-star systems during this survey was a definitive effort. Great accuracy was required; many of these stars were very close to each other, making the measurements of their orbits tricky. The resulting book, *The Binary Stars*, was published in 1918, with a revised edition in 1935 and a reprinted edition in 1964. In this work, he provided a historical sketch of binary stars, including the discovery of the variability of Algol by another deaf astronomer, **John Goodricke** in York, England. Aitken also reported on the statistical analyses of the data from his own orbital measurements. He insisted on the necessity for longitudinal studies. Repeated observations were required for accurate orbital determination, including period, eccentricity of orbit, and the orientation of orbit planes relative to our direction of observation. Aitken particularly emphasized the precaution of making measurements only when the observing conditions are good, to avoid misleading results.

The culmination of Aitken's career was in 1920, when he combined the observational data given to him by Eric Doolittle with his own. Aitken updated **Sherburne Burnham**'s 1906 catalog, and, in 1932, published *A New General Catalogue of Double Stars within 120° of the North Pole*. In preparing this volume, he compared his list of 5,400 double stars with the great *Henry Draper Catalogue*. Aitken's *New General Catalogue* is considered a lasting monument to his work.

Aitken received honorary doctoral degrees from the University of the Pacific (1903), Williams College (1917), University of Arizona (1923), and University of California at Los Angeles (1935). He was awarded the Lalande Gold Medal from the French Academy of Sciences (1906), the Bruce Gold Medal from the Astronomical Society of the Pacific (1926), and the Royal Astronomical Society's Gold Medal (1932). Aitken was elected to the United States National Academy of Sciences in 1918 and held membership and offices in many other professional societies, most notably as president of the Astronomical Society of the Pacific in both 1898 and 1915, the vice president of the American Astronomical Society from 1924 to 1931 (and president from 1937 to 1940), and president of the Pacific Division of the American Association for the Advancement of Science in 1925. He was the first president of the Commission on Double Stars in the International Astronomical Union. As editor of publications for the Astronomical Society of the Pacific for many years, Aitken achieved a level of genuine career satisfaction. Through publication, he had opportunities to converse with the general public by writing about the wonders of the heavens without the stress of the face-to-face communication that had dampened his early efforts.

A minor planet (3070) Aitken and a lunar crater on the Farside are named in his honor.

Harry G. Lang

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al-Bannāʾ

➔ Ibn al-Bannāʾ: Abū al-ʿAbbās Aḥmad ibn Muḥammad ibn ʿUthmān al-Azdī al-Marrākushī

al-Hāʾimʾ

➔ Ibn al-Hāʾim: Abū Muḥammad ʿAbd al-Ḥaqq al-Ghāfiqī al-Ishbīlī

al-Haytham

➔ Ibn al-Haytham: Abū ʿAlī al-Ḥasan ibn al-Ḥasan

al-Kammād

➔ Ibn al-Kammād: Abū Jaʿfar Aḥmad ibn Yūsuf ibn al-Kammād

al-Khatīb al-Umawī al-Qurṭubī

➔ Umawī: Abū ʿAlī al-Ḥasan ibn ʿAlī ibn Khalaf al-Umawī

al-Majdī

➔ Ibn al-Majdī: Shihāb al-Dīn Abū al-ʿAbbās Aḥmad ibn Rajab ibn Ṭaybughā al-Majdī al-Shāfiʿī

al-Raqqām

➔ Ibn al-Raqqām: Abū ʿAbd Allāh Muḥammad ibn Ibrāhīm ibn ʿAlī ibn Aḥmad ibn Yūsuf al-Mursī al-Andalusī al-Tūnisī al-Awsī ibn al-Raqqām

al-Ṣaffār

➔ Ibn al-Ṣaffār: Abū al-Qāsim Aḥmad ibn ˁAbd Allāh ibn ˁUmar al-Ghāfiqī ibn al-Ṣaffār al-Andalusī

al-Ṣalāḥ

➔ Ibn al-Ṣalāḥ: Najm al-Dīn Abū al-Futūḥ Aḥmad ibn Muḥammad ibn al-Sarī ibn al-Ṣalāḥ

al-Samḥ

➔ Ibn al-Samḥ: Abū al-Qāsim Aṣbagh ibn Muḥammad ibn al-Samḥ al-Gharnāṭī

al-Shāṭir

➔ Ibn al-Shāṭir: ˁAlā’ al-Dīn ˁAlī ibn Ibrāhīm

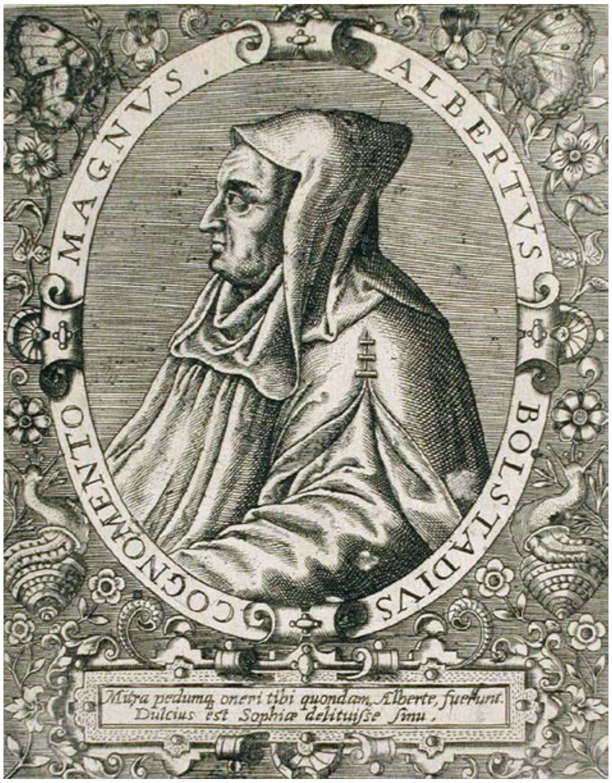
Albategnius [Albatenius]

➔ Battānī: Abū ˁAbd Allāh Muḥammad ibn Jābir ibn Sinān al-Battānī al-Ḥarrānī al-Ṣābi’

Albert the Great

Born **Lauingen, (Bavaria, Germany), *circa* 1200**
Died **Cologne, (Germany), 1280**

Albertus Magnus is traditionally credited with the introduction of **Aristotle**'s philosophy into the Christian West. By doing so he initiated a period of concern with natural-philosophical questions that had been absent from the Neoplatonist thought dominating Christianity up to that time (and which still played a crucial role in Albert's own thought).



Albertus entered the Dominican order in 1223, studying at Padua, Bologna, and Paris. He taught at the University of Paris from 1245 to 1248, when he moved to Cologne, where he spent the remainder of his life. Albertus probably became familiar with the Aristotelian corpus in the 1240s at the priory of Saint Jacques in Paris. The Arab commentators from whom he learned his Aristotle worked in an environment in which astronomical questions were taken very seriously, and, atypically for his time, Albertus himself pursued such questions.

Albertus developed two notable doctrines. The first was the view that the Milky Way was not a sublunary exhalation (as Aristotle had urged) but rather a configuration of stars. He was cited by defenders of this view, most notably Gaetano di Thiene, in the 15th and 16th centuries.

Second, like many medieval and renaissance natural philosophers, Albertus was unhappy about the eccentrics and epicycles of **Ptolemy**, wondering what physical rationale they could have. Despite the difficulties in reconciling them with the observed motions of celestial bodies, particularly those of the planets, Albertus preferred the homocentric account of celestial motions. The question is complicated, however, by the fact that he distinguished between the mathematical accounts of celestial motion and the natural-philosophical (physical) ones. To a large extent this prevents the two sets of considerations coming into conflict, so that the irreconcilability of the physical arguments on the one hand, and the mathematical and observational arguments on the other, is not as evident as it became in the 16th century. Indeed, in some respects Albert set in motion a very problematic division of responsibilities with regard to astronomical questions, which fitted in well with the delicate balancing act that the introduction of Aristotelian philosophy required, but which turned out to be quite artificial.

Albert's natural-philosophical and astronomical writings are to be found principally in his commentaries on Aristotle.

Stephen Gaukroger

Alternate name

Albertus Magnus

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Albertus Magnus

➔ **Albert the Great**

Albertus Blar de Brudzewo

➔ **Brudzewo, Albertus de**

Albert Brudzewski

➔ **Brudzewo, Albertus de**

Albrecht, Sebastian

Born **Milwaukee, Wisconsin, USA, 22 August 1876**
Died **probably Albany, New York, USA, 9 April 1957**

American observational astronomer Sebastian Albrecht was the son of John and Anna Mary Schiessel Albrecht. He married Violet E. Standen in 1910. They had two children. Albrecht was educated at the University of Wisconsin (B.S.: 1900), where he studied under **George Comstock**, and at Lick Observatory (fellow: 1903–1906) and the University of California, where he received a Ph.D. in 1906 for work on the spectra of variables stars Y Ophiuchi and T Vulpeculae with **William Campbell**.

From 1900 to 1903 Albrecht taught high-school science in West Bend, Wisconsin. From 1906 to 1910 he was an assistant astronomer at the Lick Observatory, and in 1908 he took part in the Lick Observatory solar-eclipse expedition to Flint Island in the Pacific; in 1909 he was part of a Lick Observatory expedition to observe from the summit of Mount Whitney. From 1910 to 1912 Albrecht joined another former Lick astronomer, **Charles Perrine**, as astronomer at the Argentine National Observatory at Córdoba. During the year 1912/1913, Albrecht was assistant professor of astronomy at the University of Michigan and took part in recording the spectra of peculiar variable stars and worked on the reduction of his own earlier observations. In 1913 he moved to the Dudley Observatory, where he spent the rest of his career under the auspices of the Carnegie Institution of Washington. Albrecht retired from the Dudley Observatory in 1937. He returned to "active duty" as an instructor in the Navy Program at Rensselaer (1944–1947).

Albrecht was a fellow of the American Association for the Advancement of Science and member of the American Astronomical Society, the Mexican Astronomical Society, and Sigma Xi. In 1930 he was the secretary of the American Astronomical Society and in 1935 was chair of the committee on standards of wavelength for the American section of the International Astronomical Union.

Albrecht's dissertation was a spectrographic investigation of two variable stars. From this study Albrecht derived his lifelong interest in the precise measurement of wavelengths and the factors that affected their measurement and also changes in wavelength as well. He felt that such studies would affect the accuracy of stellar radial velocity determinations, motions in the line of sight toward or away from the observer, and also studies of the conditions at various levels of stellar atmospheres. The work at Dudley Observatory, however, was centered on the accurate determination of stellar positions and proper motions.

The most important product of Albrecht's work at Dudley was participation in compiling a catalog of positions and brightnesses of 33,342 stars with senior author **Benjamin Boss**. Published in 1936–1937, this was one of the first catalogs to tabulate stars with equinox 1950 coordinates.

There are some records of his later career in the archives of the Dudley Observatory.

Rudi Paul Lindner

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Albumasar

❯ **Abū Maˁshar Jaˁfar ibn Muḥammad ibn ˁUmar al-Balkhi**

Albuzale

❯ **Abū al– Ṣalt Umayya ibn $^{\grave{A}}$Abd al-$^{\grave{A}}$Azīz ibn Abī al-Ṣalt al-Dānī al-Andalusī**

Alcabitius

❯ **Qabīṣī: Abū al-Ṣaqr ˁAbd al-ˁAzīz ibn ˁUthmān ibn ˁAlī al-Qabīṣī**

Alchvine

❯ **Alcuin**

Alcuin

Born **near York, England, *circa* 735**
Died **Tours, (Indre-et-Loire), France, 19 May 804**

Alcuin, a universal scholar, educator, and key counselor of Charlemagne, is best known for his astronomical studies and observations, which led to the Carolingian reform of the calendar.

Of noble Anglo-Saxon lineage, Alcuin was educated at York's cathedral school by students of the Venerable **Bede**, as well as Colgu from Ireland. He taught at this school from 765 and became its head in 778. While acquiring books on the Continent, he met Charlemagne in Parma in 781. The Frankish king, having heard of Alcuin's learning and teaching abilities, invited him to lead his Palace school at Aachen.

Moving to Francia in 782, Alcuin became the key counselor of Charlemagne for science, education, and church matters. He taught the King, his family, and the Frankish nobles, reforming the Palace school according to the Anglo–Saxon principle of the seven liberal arts. Alcuin instigated the *Admonitio generalis* of 789, now considered instrumental for the Carolingian renewal of education.

Alcuin produced many didactic writings and probably also the oldest collection of mathematical problems in Latin. He is best known for his verses and his large corpus of letters, written mainly after 796, when he became abbot of Saint Martin's in Tours. The correspondence between Alcuin and Charlemagne (54 letters) includes nine letters on astronomy and calendrical reckoning, called "*computus*" (letters 126, 143, 144, 145, 148, 149, 155, 170, and 171 in the *Epistolae*); six such letters are lost.

It was long assumed that Alcuin was the author of four short anonymous writings: *Ratio de luna*, *De bissexto*, *De saltu lunae*, and *Calculatio Albini magistri*, but recent research indicates that only the first (*circa* 798) was certainly his. The *Calculatio* of 776 is based on an Irish text of 675 and provides easy instructions to determine the months and weekdays of the Easter full moon.

Dating the movable feast of Easter (the first Sunday after the first full moon in spring) was the chief computistic problem of the Middle Ages. This was in fact a complex problem related to the 19-year lunar cycle and the 28-year solar cycle comprising a 532-year Easter cycle. The full moon dates fall on the same days of the months after 19 years, the weekdays after 4 times 7 years, due to the intercalated day.

The most important astronomical-computistic contribution of Alcuin concerned the "moon-leap" or *saltus lunae*. Estimating a lunar month of 29 or 30 days, the 19-year cycle would have 6,726 lunar days, although 19 solar years (of 365 days) would have 6,935 solar days. To reconcile the difference, 7 lunar months of 30 days were intercalated (6,935 lunar days), requiring removal of the supernumerary day at the end of the 19-year cycle.

In his letter 126 (797) Alcuin opted for the *saltus lunae* on 25 November, following Roman tradition. But Charlemagne's new counselors wanted to follow Alexandrian tradition, starting the legal year on 1 September and fixing the *saltus* on 30 July. Alcuin was irritated and in letter 145 (798) called his competitors *aegyptiaci pueri*, "Egyptian Boys," and challenged them with five questions on the calculation of the lunar cycles. Alcuin also promised Charlemagne that he would write up his own treatise on the *saltus lunae*, but it is lost.

In letter 148 Alcuin calculated when the Sun entered each of the 12 signs of the zodiac, to explain why a solar day must be intercalated every 4 years (the *bissextus*). In letter 149 Alcuin reported about the reappearance of Mars, after the Sun had concealed it, on 18 July 798, at the time he reobserved Sirius. This observation found its way into the Court Annals, which subsequently reported eclipses of the Sun and the Moon, and other notable planetary configurations.

Charlemagne wanted Alcuin to interpret the reappearance of Mars as a good omen for his Saxon campaign, but in letter 155 Alcuin rejected this and gave a different but erroneous explanation, that Mars had stood still for 1 year in the zodiacal sign of Cancer, and was not visible together with Cancer.

Charlemagne had also asked Alcuin to calculate when the Moon entered each of the 12 signs of the zodiac. These calculations are found in *Ratio de luna*, forming an appendix to a later letter by Alcuin. It brings the course of the Moon into mathematical correspondence with that of the Sun, using the formula of "9 lunar hours = 5 solar days."

In letter 170 (799) Charlemagne enquired why the Moon on 18 March did not yet have the appearance of an increasing half-moon in the zodiacal position 7° of Gemini. In letter 171 Alcuin calls Charlemagne's calculations on Moon and *bissextus* a "perfection of my own calculations." But this is not identical to the anonymous *De Bissexto*, which stems from the same author as *De saltu lunae*.

Charlemagne commissioned Alcuin, as the expert on the *computus* (probably in 789), to write a standard work, resulting in his *Libellus annalis*, which is lost except for the dedication verses. But three Carolingian manuals on the *computus* have survived:

1. The short *Annalis libellus* of 793, probably not identical with Alcuin's *Libellus annalis*.
2. The first compendium on calendrical reckoning, the seven-book computus written at the Court in 809–812, called *Aachen Encyclopedia*.
3. The three-book computus of 818, assembled at Salzburg.

The mediocre *Annalis libellus*, containing Alcuin's *Calculatio*, prescribes the Roman *saltus* in November; however, it also refers to Alexandrian tradition. But the "Aachen Encyclopedia," probably edited by Adalhard of Corbie and sponsored by Charlemagne, and including Alcuin's tracts *Calculatio* and *Ratio de luna*, is the most important Carolingian contribution to the *computus*; it does not take sides between Alexandrian and Roman reckoning. The three-book computus, assembled by Arno of Salzburg, encompasses the full Roman tradition propagated by Alcuin in the form of a perpetual lunar cycle calendar.

Alcuin's astronomical observations of the Moon, Sirius, and especially Mars and its "vanishing," initiated systematic astronomical recording at the Frankish Court. His teachings inspired Charlemagne's scholars to detailed study of planetary motions in a geocentric system that led to new astronomical diagrams visualizing Plinian planetary theory. In sum, Alcuin's research and teaching made the Carolingian reform of the calendar possible, to standardize calendrical reckoning and chronology for the next three centuries.

Paul L. Butzer and *Kerstin Springsfeld*

Alternate names

Alchvine
Ealhwine
Flaccus Albinus

Acknowledgement

The authors are grateful to Karl W. Butzer (R.C. Dickson Centennial Professor, Austin, Texas) for his critical reading of the manuscript.

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Alden, Harold Lee

Born **Chicago, Illinois, USA, 10 January 1890**
Died **Charlottesville, Virginia, USA, 3 February 1964**

Although the Yale University Observatory station in South Africa was the idea of **Frank Schlesinger**, it was American Harold Alden who took most of the tens of thousands of photographic exposures that led to the determination of hundreds of new stellar parallaxes (1925–1945). Alden was later the director of the Leander McCormick Observatory.

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Alexander, Arthur Francis O'Donel

Born **England, 9 November 1896**
Died **Dorchester, England, 29 January 1971**

Arthur F. O'Donel Alexander, an amateur astronomer, applied his outstanding organizational and analytical abilities to the collation of planetary observations. His books on Saturn and Uranus are models of careful historical research and masterly presentation and are still accepted as standard reference works on these two planets. An historian by training, Alexander was an educational administrator by profession. He obtained his B.A. degree in 1918 from University College, Exeter, England, to which he had won an open scholarship in 1915. He was the first student of the college to secure first-class honors in history. Alexander taught for 3 years in the United Kingdom, and then moved to Japan where, until 1924, he instructed science students in English at the Matsuyama National College. On his return to the United Kingdom he took up the posts of secretary for education and executive officer of Londonderry County Borough Authority, Northern Ireland. In 1930, Alexander was appointed assistant director of Education to the Dorset County Council, England, a post he retained until his retirement in 1961. He was awarded a University of London external M.A. degree in 1927 and a doctorate in philosophy, also from the University of London, for a thesis on the early part of the One Hundred Years War.

Alexander joined the British Astronomical Association [BAA] in 1937, and contributed regularly to the work of its solar, lunar, planetary, comet, and variable star sections. His natural flair for analysis led him to devise new methods of utilizing statistics to study sunspots, the solar cycle, and solar physics generally. He applied statistical techniques to the *Greenwich Photoheliographic Results* to derive valuable results on the areas, distribution, and frequency of sunspots. His analyses were summarized in four papers published in the *Journal of the British Astronomical Association* between 1944 and 1947.

With most regular observers engaged in war service, Alexander organized a team of observers who still had access to their telescopes to cover the Mars opposition of 1941, the most favorable opposition for observers in the United Kingdom since 1926. The effort was a complete success; a full report on the 1941 Mars opposition appeared in 1951. This demonstration of his abilities established his future role in the work of the association.

In 1946 Alexander was appointed director of the Saturn Section and built a large and vigorous team of observers. His 1953 paper "Saturn's Rings – Minor Divisions and Kirkwood's Gaps" is considered an important addition to the literature of the planet. In 1951 he handed over the section to his friend M. B. B. Heath, and took charge of the Jupiter Section, then in shambles. The illness of the elderly **Bertrand Peek** had forced his resignation in 1949 after many years of outstanding leadership of the Jupiter Section. Unfortunately, Peek's successor, D. W. Millar, also fell ill and provided little guidance to the section for several years. Alexander's personal standing and that of the Jupiter Section were enhanced following the discovery in 1955 of radio emissions from Jupiter, since this led to close collaboration between Alexander and radio astronomers. However, illness obliged Alexander to hand over the section to W. E. Fox in 1957.

After his withdrawal from active sectional leadership, Alexander coupled his historical research skills with his profound knowledge of the planet Saturn to produce a book-length monograph on that planet. The book, subtitled appropriately as "a history of observation, theory and discovery," discusses these three aspects of our knowledge of Saturn from ancient times to the most modern research available in the early 1960s. A similar effort with respect to the planet Uranus was published a few years later, though in that case Alexander's personal involvement in the recent observational history was more limited. Alexander's two monographs, *The Planet Saturn* and *The Planet Uranus*, remained useful resources late in the 20th century.

Alexander, a talented linguist and very active in astronomical education, had global links with both amateur and professional astronomers. He led a small party of BAA members to the Pic-du-Midi Observatory in 1947, and had honorary membership in the Société Astronomique de France. From 1951 to 1957 he represented the BAA on the British National Committee for Astronomy. Alexander was also a member of the International Astronomical Union Commission 16 (Physical Study of Planets and Satellites), and represented the United Kingdom on the subcommittee set up to revise the nomenclature of Mars. In 1954 he went to Sweden as a member of the joint Royal Astronomical Society/BAA Eclipse Expedition. In addition to contributing monographs on Saturn and Uranus, Alexander contributed important chapters on the planets and minor planets to Dent's *Astronomy for Everyman*.

The BAA honored Alexander in 1962 with its Walter Goodacre Medal and Award.

Richard Baum

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Alexander, Stephen

Born **Schenectady, New York, USA, 1 September 1806**
Died **Princeton, New Jersey, USA, 25 June 1883**

A frequent observer of solar eclipses, Stephen Alexander also published two major papers that developed out of his interest in **Simon de Laplace**'s nebular hypothesis: one on the development of nebulae and star clusters and the other on harmonies in the Solar System. His concern for harmonies led him to be called "the American Kepler," and it was evident that the title was not entirely complimentary.

After graduating from Union College in 1824, Alexander taught at Yates Polytechnic, a vocational school in Chittenango, New York. His earliest documented astronomical observations date to 1825. In May 1830 his younger sister Harriet married **Joseph Henry**, their first cousin. Thereafter, Alexander's life and career were bound up with those of Henry, who became America's most important scientist. Alexander left Yates within a few months of his sister's wedding to reside with the Henrys in Albany. When Henry accepted a professorship at the College of New Jersey (now Princeton University) in 1832, Alexander followed to attend the Princeton Theological Seminary. A year later he became a tutor at the college. In 1834 Alexander became adjunct professor of mathematics; he also took responsibility for teaching astronomy in 1836. In 1840 he was appointed professor of astronomy, and remained on the faculty at Princeton University until his retirement in 1876.

Alexander was married twice. In 1836 he married Louisa Meads of Albany, with whom he had three daughters. Three years after her death, in 1847 he married Caroline Forman of Princeton. They had two daughters.

Although eclipses were always an interest, Alexander's most important paper on the topic came early in his career. At the 1843 centennial celebration of the American Philosophical Society, an event that attracted the American scientific elite, Alexander presented his "Physical Phenomena Attending Solar Eclipses." Characteristically, he attempted to reduce a wide variety of observations – both his and those he found from an extensive literature search – to a few simple explanations or "laws." He concluded that there was no evidence that any body in the Solar System except the Earth possessed an atmosphere. This paper was later criticized by **Charles Young** for its failure to provide "sufficient discrimination between the real and imaginary." All too often Alexander had relied on a single observation by a relatively untrained observer, an acceptable practice among American astronomers in the 1830s, but not so a half century later.

In 1845 Alexander participated in what would be his most important astronomical observations. He and Henry measured the relative temperature of sunspots by placing a thermoelectric device at the focus of the Princeton 3½-in. Fraunhofer refractor, demonstrating conclusively that the sunspots were relatively cooler. They also produced data showing that the solar limb was cooler than the solar center. The only publication that resulted from the observations was a brief description in the *Proceedings of the American Philosophical Society,* and Alexander did not carry on the research after Henry abandoned it.

Despite what a later generation thought of his work, and his thin list of publications, by contemporary standards Alexander was a significant figure in American astronomy. He served on a variety of committees for the American Association for the Advancement of Science, and was president at its 1859 meeting. Alexander was selected as one of the original members of the National Academy of Sciences, established in 1863. In part, his visibility was no doubt due to his family connections. It is also important to take into account Alexander's well-documented reluctance to transform his many oral presentations into publications, which resulted in a higher awareness of his work among contemporaries than among later astronomers. His contemporary reputation also rested on his 1852 publication in the *Astronomical Journal* entitled "On the Origin of the Forms and the Present Condition of Some of the Clusters of Stars and Several of the Nebulae." This eight-part paper argued that some of the stellar clusters and spiral nebulae were disintegrating stars, not stars in the process of formation, as was widely held.

Alexander's most important paper – in his own mind and in the sense that it represented a significant part of his life's work – did not appear until 1875, at the end of his career, but was the product of three decades of thought about the nebular hypothesis in general, and the ratios of planetary distances and those of planetary satellites in particular. "Certain Harmonies of the Solar System," published by Henry's Smithsonian Institution, established "laws" for the distances of the planets from the Sun and the distances of the satellites from the planets and demonstrated that the nebular hypothesis accounted for these laws. By the time Alexander had published, however, the deficiencies in the nebular hypothesis were very evident. It was a paper that appeared too late to add very much to Alexander's reputation.

When Alexander began his eclipse observations in 1825, American astronomy was a minor part of the world community. By his death, the American community was on the edge of becoming a peer of the European communities. He was one of the pioneers, and his education, career, and publication record were typical of the American college professor of his generation.

Marc Rothenberg

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Alfarabius

➜ **Fārābī: Abū Naṣr Muḥammad ibn Muḥammad ibn Tarkhān al-Fārābī**

Alfonsi, Petrus

Flourished **(Spain), 1106–1120**

Petrus Alfonsi is likely to have been instrumental in introducing Arabic astronomy to Christian scholars such as **Walcher of Malvern** and **Adelard of Bath**, and thus played a key role in prompting the whole-scale translation of Arabic mathematical and astronomical learning in the 12th century.

Alfonsi was educated as a Jew in an Arabic milieu in Huesca (Aragon) in the Islamic kingdom of Zaragoza; but, after the Christian conquest of Huesca in 1096, he converted to Christianity, and was baptized on 29 June 1106. Thereafter he traveled in France and England, advertising himself as a "teacher of astronomy," but perhaps returned to Spain (if he can be identified with a "Peter of Toledo") later in his life. Alfonsi was the earliest scholar to bring learned Arabic cosmological and astronomical knowledge to Latin-reading Christians.

Much astronomical and cosmological information is included in his popular *Dialogus contra Iudaeos* (Dialogue against the Jews) in which his old Jewish self, Moses, discusses the relative merits of Judaism and Christianity with his new Christian self, Petrus. In another work, written in the form of a letter addressed to "the Peripatetics of France," he extols the importance of astronomy, and the superiority of Arabic astronomy to that of Latin scholars of his time, and invites students to study the subject with him. The date and place of composition of these two works are unknown.

The two works that Alfonsi devoted specifically to astronomy, however, were both written in the West Midlands of England, and one of them mentions the collaboration of Walcher, prior of the Benedictine abbey of Great Malvern, near Worcester. The first of these is a short text on the movement of the Moon and the cause of eclipses, called in full "The opinion of Petrus, called 'Alfonsus,' concerning the lunar node, which lord Walcher, prior of the church of Malvern, translated into Latin." It mentions the date 1 April 1120 in an example. Second is a version of the astronomical tables of **Muhammad Ibn Musa al-Khwārizmī**, with a starting point of 1 October 1116, and preceded by a prologue in praise of astronomy that Petrus cites in his letter to the Peripatetics of France. These are the earliest complete astronomical tables known in the Latin Middle Ages. They are not, however, without problems, since, although the starting values (*radices*) of the movements of the Sun, the Moon, and the planets have been calculated from al-Khwarizmi's data quite accurately, the subsequent values have been clumsily and erroneously computed and ineptly adapted to the Latin calendar. Moreover, the canons to the tables in the two extant manuscripts have been combined with chapters from another version of the same astronomical tables of al-Khwarizmi (that by Adelard, which retains the Arabic calendar).

Charles Burnett

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Alfonso X

Born **Castile, (Spain), 1221**
Died **Castile, (Spain), 1284**

King Alfonso X reigned from 1252 until 1284. He was a patron of literature and learning and made a great effort to recover Arabic and, very especially, Andalusian astronomical materials by translating them into Spanish, thus becoming a pioneer in the use of the vernacular as a scientific language. Later, probably coinciding with the period (1256–1275) in which he aspired to become the Emperor of Germany, he had some of these works retranslated into Latin. The highest expression of this cultural policy can be found in his *Alfonsine Tables*, in which we find an aspiration to universality very much in keeping with a project of producing a set of "imperial" astronomical tables.

His collaborators were a Muslim convert to Christianity (Bernardo el Arábigo), and eight Christians, of whom four were Spaniards (Fernando de Toledo, Garci Pérez, Guillén Arremón d'Aspa, and Juan d'Aspa), and four Italians (John of Cremona, **John of Messina**, Petrus de Regio, and Egidius Tebaldi of Parma). The Italian group seems to have been involved mainly with the retranslations into Latin. To these one should add a very important group of five Jews (Yehudah ben Mosheh, **Isaac ibn Sid** called Rabiçag, Abraham Alfaquín, Samuel ha-Leví, and a certain Mosheh). Two (Yehudah and Rabiçag) take pride of place due to the number and importance of the works they wrote; in particular, they were the authors of the *Alfonsine Tables*. Of these two, only Yehudah was a translator, while Rabiçag wrote original works and built scientific instruments. Alfonso failed in his attempt to persuade a Muslim scientist, Muḥammad al-Riqūṭī, to join his team; they probably met on the king's visit to Murcia in 1271.

Alfonsine translations are based on Arabic works that had not been previously translated into Latin. It is conceivable that these sources were found in libraries that came under Christian control as a result of the conquests of Cordova (1236) and Seville (1248) by Alfonso's father king Fernando III. Some of these translations preserve Andalusian astronomical works that would have been lost otherwise; this is the case, for example, of the *Libro de las Cruzes* (Book of crosses), a late Latin astrological handbook based on a versified Arabic version that had been written in the first half of the 9th century and subsequently revised by a certain ʿUbayd Allāh in the 11th century. Other works that are only known through Alfonso's translations are the *Lapidario* (a book on the magical applications of stones) written by the otherwise unknown author of *Abolays*, the two books on the construction of equatoria written by **Ibn al-Samḥ** (died: 1035) and **Zarqālī** (died: 1100), **ʿAlī ibn Khalaf**'s book on the use of the plate for all latitudes (*Lámina Universal*, Toledo, 11th century), and Zarqālī's treatise on the construction of the armillary sphere.

King Alfonso seems to have devised a well-structured project for producing two collections of translations and original works. The first collection was devoted to magic and contained the *Picatrix* (only the Latin text is extant), the series of lapidaries, and the *Libro de la mágica de los signos*. The second was an astronomical and astrological collection and in it we find the well-known *Libros del Saber de Astronomía*, **Ibn al-Haytham**'s *Configuration of the Universe*, **Battānī**'s *Canons* (Instructions for the use of his tables), the treatise on the use of the *Cuadrante sennero* (sine quadrant?), the *Alfonsine Tables*, **Ptolemy's** *Quadripartitum* with the commentary by ʿAlī ibn Ridwān, the *Libro conplido en los iudizios de las estrellas* (*Kitāb al-Bāriʿ fī aḥkām al-nujūm*) by ʿAlī ibn Abī al-Rijāl, and the anonymous *Libro de las Cruzes*.

The first book of the *Libros del Saber de Astronomía* (*Ochava Espera*) is a treatise on uranography partially based on **Ṣūfī**. The rest of the collection is composed of treatises on astronomical instruments that are mainly analogical calculators (celestial sphere, spherical and plane astrolabe, saphea, and plate for all latitudes) whose main purpose is to provide graphic solutions for problems of spherical astronomy and astrology that can be applied to the casting of a horoscope. The purpose of the rest of the instruments (quadrant of the type called *vetus*, sundial, clepsydras) is to determine the time, something which is also needed to cast the horoscope. The king wished to have a treatise on the construction and another one on the use of each of these instruments. If an adequate Arabic source was available, Alfonso ordered its translation. Otherwise, an original treatise was written, usually by Rabiçag. For obvious reasons, most of the Alfonsine works that are original are concerned with the construction of instruments, for such texts are more difficult to find than treatises on their use.

We also find in the *Libros* the two treatises on equatoria, instruments whose purpose is to provide approximate calculations of planetary longitudes using Ptolemaic planetary models drawn to scale that allow a graphical solution of a problem that is, again, essential for casting a horoscope. Evidently, Alfonso's tabular works (Zarqālī's *Almanach*, Battānī's *Canons*, and the *Alfonsine Tables*) have exactly the same object.

A last group of Alfonsine works comprises works on judicial astrology (*Quadripartitum*, *Libro de las Cruzes*, *Libro conplido*), which allow the reader to interpret the horoscope and predict the future as well as works on magic whose purpose is to fabricate talismans in propitious astrological conditions in order to modify this same future. When seen from the point of view of a king who was extremely interested in both astrology and magic, his astronomical, astrological, and magical works form an impressive unit that seems to be the result of a well-designed plan. Only two works fall outside this frame; one of them is the aforementioned *Ochava Espera* that contains, apart from a description of the 48 Ptolemaic constellations, enough connections with the lapidaries and other magical texts to consider it as an exception. The second is the translation of Ibn al-Haytham's *Cosmography,* which corresponds to a type of theoretical interest not all that common in the corpus of Alfonso X.

The *Alfonsine Tables* represents Alfonso's most important astronomical work. However, it poses numerous problems, the most obvious of which is the existence of two different versions (one in Spanish, another in Latin). On the one hand, we have the Spanish text of a set of canons without the corresponding collection of numerical tables. These canons have a prologue in which it is said that their authors are Yehudah ben Mosheh and Rabiçag; the text was written between 1263 and 1272; 200 years after the observations of Zarqālī, the king had ordered the construction of the necessary astronomical instruments to make observations in Toledo; and the two astronomers, following the royal orders, made observations of the Sun, planetary conjunctions, and solar and lunar eclipses. Unfortunately, it is difficult to check the veracity of these assertions except for three lunar eclipses (one in 1265 and two in 1266) and one solar (1263) eclipse, on which we have a report transmitted by Isaac Israeli (*circa* 1310). The few numerical parameters mentioned in the canons or in the rest of the Alfonsine works extant in Spanish derive from the *Toledan Tables* or from the work of the Maghribī astronomer **Ibn Isḥāq** (flourished: *circa* 1193–1222). On the other hand, in the Latin tables one finds new parameters that might be the result of the alleged Alfonsine observations.

In about 1320, a new set of *Alfonsine Tables* appeared containing numerical tables with titles in Latin but without the canons that could be attributed to the Alfonsine circle. Many authors from various parts of Europe (beginning with the Parisian group of **John of Saxony**, **John of Murs**, and **John of Linières**) wrote original canons allowing the use of the numerical tables. The tables were enormously successful and became standard in Late Medieval and Early Renaissance Europe until 1551, when **Erasmus Reinhold** published the *Prutenic Tables*. **Nicolaus Copernicus** used parameters derived from the *Alfonsine Tables* in his *Commentariolus*, and the Alfonsine tropical year of 365 days, 5 hours, 49 minutes, and almost 16 seconds was the mean tropical year used in the *De revolutionibus* and became the basis for the Gregorian reform.

The total lack of information about the tables between *circa* 1272 and *circa* 1320, and their complicated textual history between the 14th and 16th centuries, when every version or adaptation of this work added new tables to the original corpus, has recently led to a number of different opinions among historians. At least one (Poulle) has denied any relation between the Latin tables and the work of Alfonso X. Others (North, Goldstein, Chabás, Mancha, and Samsó) have discussed this point and argued in favor of the presence of materials in the Latin tables that have a clear relation to others attested in the undisputed Spanish works of Alfonso X. In the opinion of this author, Yehudah ben Mosheh and Rabiçag wrote the Spanish canons under the influence of Zarqālī and the *Toledan Tables*. Later they began a new set of tables following Battānī's tradition. In this second set, the language used was Latin, reflecting the imperial aspirations of King Alfonso. This is not the interpretation adopted by Chabás and Goldstein in a recent book: they believe that the revision was made in Paris, on the basis of the Alfonsine materials mainly represented by the Castilian canons. Whatever the truth, it seems a fact that the *Alfonsine Tables* are the result of the work of the Alfonsine collaborators and that they mark the starting point of an original European astronomy that was still strongly influenced by an Arabic tradition.

Julio Samsó

Alternate names

Alfonso el Sabio
Alfonso the Learned
Alfonso the Wise

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Alfonso el Sabio

➲ **Alfonso X**

Alfonso the Learned

➲ **Alfonso X**

Alfonso the Wise

➲ **Alfonso X**

Alfvén, Hannes Olof Gösta

Born **Norrköping, Sweden, 20 May 1908**
Died **Djursholm, Sweden, 2 April 1995**

Swedish–plasma physicist and astrophysicist Hannes Alfvén is commemorated in Alfvén waves and the Alfvén velocity at which they travel. He shared the 1970 Nobel Prize in Physics for his contributions to plasma physics, especially magnetohydrodynamics, and can be regarded as the founder of the field of cosmic electrodynamics. Hannes Alfvén was the son of Anna-Clara Romanus (a physician) and Johannes Alfvén. He and his wife, Kerstin Erikson (married: 1935), had five children.

Alfvén developed an early interest in astronomy, reading the *Astronomie Populaire* by **Camille Flamarion** as a teenager, and

in radio communication, building his own receiver. He was educated in mathematics and physics at the University of Uppsala, receiving a Ph.D. in 1934 for work on ultra-high frequency electromagnetic oscillations. In 1940, Alfvén was appointed professor of electromagnetic theory and electric measurements at the Royal Institute of Technology in Stockholm, where he established a vigorous school of electronics, partly directed toward technical applications. In 1945, he was appointed to a personal chair of electronics, renamed plasma physics in 1963, from which he retired in 1973. From 1967 onward Alfvén held joint appointments at Stockholm and at the University of California at San Diego as research physicist until 1973, as professor during 1973–1975, and as professor emeritus of electrical engineering and computer science during 1975–1988, when he returned permanently to Sweden.

Alfvén created the research field of cosmical electrodynamics, using his knowledge of experimental and theoretical physics to establish that, in addition to gravity, electromagnetic forces play a significant role in a variety of astrophysical processes. His first contributions were collected in the first edition (1950) of his book *Cosmical Electrodynamics*, with four chapters on general methods followed by three chapters on applications to specific astrophysical problems. A later edition, *Cosmical Electrodynamics – Fundamental Principles* by Alfvén and Fälthammar (1963), has been extensively used in graduate education. Alfvén's cosmogonic work was presented in his 1953 book *Origin of the Solar System*, and greatly extended in the 1976 book *Evolution of the Solar System*, written jointly with the chemist **Gustaf Arrhenius**.

Alfvén's earliest astrophysical interests were directed toward theory and observations of cosmic rays. In 1933 he published a paper on an electromagnetic origin of cosmic rays, a subject to which he repeatedly returned during the following 25 years. Alfvén (1940) introduced the method of separating the motion of a charged particle in a magnetic field into a fast gyration transverse to the magnetic field and a slower drift of the center of this gyration, which he called the "guiding center." This led to a drastic simplification, which has become a fundamental tool in the entire field of plasma physics, from cosmical plasmas to laboratory plasmas and controlled fusion research. A number of scientists developed the highly sophisticated adiabatic theory of charged particle motion, which is today indispensable in modern plasma physics. The rapid transverse motion gives rise to synchrotron radiation, which was predicted in cosmic contexts by Alfvén and Nicolai Herlofson in 1940 and discovered in the 1940s and 1950s in solar radio emission and optical radiation from supernova remnants.

Alfvén noticed that in our Galaxy the energy density of cosmic rays is about the same as that of starlight (the Sun excluded). Considering reasonable sources and sinks of these two energies, and the isotropy of cosmic radiation, he predicted in 1937 the existence of a galactic magnetic field due to electric currents carried by the interstellar plasma – a prediction later amply verified by the polarization of starlight scattered by interstellar dust (discovered by **John Hall** and **William Hiltner**) and by the synchrotron nature of galactic radio emission.

In addition to his theoretical work, Alfvén, characteristically, conducted careful observations of cosmic rays. Throughout his career he emphasized the importance of laboratory experiments as a check on theories, including theories of cosmic phenomena, because "the same laws of nature should apply everywhere".

Directing his attention to electromagnetic aspects of solar physics, Alfvén, in 1943, developed a theory of sunspots and the sunspot cycle. In the process of this work he discovered, in 1942, the existence of a new kind of waves, nowadays known as Alfvén waves. Studying fluids of high electrical conductivity, such as the solar plasma or interstellar plasma, Alfvén showed that a combination of electromagnetic theory and fluid dynamics opened a whole new field of physics: magnetohydrodynamics. Although many decades of new observations have revealed much more complicated magnetic fields in the Sun, and theories of sunspots are accordingly different, Alfvén waves and the Alfvén velocity remain indispensable concepts.

From the existence of solar magnetic fields Alfvén concluded that beams of charged particles emanating from the Sun during magnetic storms and aurorae must carry magnetic fields. He made this the basis of a new theory of magnetic storms and aurorae (1939). Decades later this radical and much-contested prediction was verified by *in situ* measurements in space.

A persistent problem in cosmogony has been that the major planets in their orbits carry 98% of the angular momentum in the Solar System and the massive Sun only 2%. In 1942 Alfvén showed that a new process of electromagnetic braking during the formation of the planetary system would very efficiently transfer angular momentum from the rotating Sun to the orbits of the nascent outer planets.

To emphasize the significance of electromagnetic forces, Alfvén coined the term Plasma Universe to represent a "new paradigm" in cosmical physics. The astronomical community gradually came, by about 1965, to accept that Alfvén had been essentially right about the importance of magnetic fields in astrophysical contexts. Curiously, he then turned around and advocated large-scale electric fields to account for properties of galaxies and diffuse matter in the Universe. This has not been generally accepted.

In addition to receiving the Nobel Prize, Alfvén received numerous awards, including the Gold Medal of the Royal Astronomical Society, the Lomonosov Medal of the USSR Academy of Sciences, the Gold Medal of the Franklin Institute, the Bowie Gold Medal of the American Geophysical Union, and the Dirac Medal of the Australian Institute of Physics. He was a member of the Royal Swedish Academy of Sciences, the Royal Swedish Academy of Engineering Sciences, the USSR Akademia Nauk, the Royal Society of London, the National Academy of Sciences, Washington, DC, and the American Academy of Arts and Sciences, Boston, as well as of the Yugoslav and Indian academies. He received honorary doctorates from the universities of Newcastle upon Tyne, Oxford, and Stockholm.

Carl-Gunne Fälthammar

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ˁAlī al-Muwaqqit: Muṣliḥ al-Dīn Muṣṭafā ibn ˁAlī al-Qusṭanṭīnī al-Rūmī al-Ḥanafī al-Muwaqqit

Born **probably Istanbul, (Turkey)**
Died **Istanbul, (Turkey), 1571**

Muṣṭafā ibn ˁAlī was one of the most important figures of 16th-century Ottoman astronomy. He was nicknamed *al-muwaqqit* (the timekeeper) because of his theoretical and practical studies of astronomical timekeeping (*ˁilm al-mīqāt)* and work on astronomical instruments, and is considered to be the founder of the Ottoman tradition of *ˁilm al-mīqāt* and practical astronomy. To a great extent Muṣṭafā ibn ˁAlī continued the movement of the Turcification of Graeco–Hellenic and classical Islamic astronomy literature that was started by **Muḥammad al-Qunawī**. He also wrote books in the field of mathematical geography.

Born in Istanbul in the early 16th century, Muṣṭafā ibn ˁAlī was educated in the wake of the reigns of Sultan Mehmet the Conqueror and Sultan Bāyazīd II (reigned: 1481–1512), during which time the sciences were nurtured. He took courses from the leading scholars of the time, including **Mīram Čelebī** who continued the tradition of astronomy established by his great grandfather **ˁAlī Qūshjī**, his friends, and students. In addition, Muṣṭafā ibn ˁAlī inherited the previous achievements of *ˁilm al-mīqāt* (timekeeping) from Muḥammad al-Qunawī, who had relied upon the work of **Khalīlī**, and **Ibn al-Shāṭir** before him. As the *muwaqqit* (timekeeper) of the Sultan Selīm I Mosque in Istanbul, Muṣṭafā ibn ˁAlī came to be known as the *Koca Saatçi* (grand timekeeper). His precise calculations for determining time were accepted as a primary source not only within the Ottoman State but also, according to Ewliyā Čelebi, in Western Europe. After 1560, he was appointed *Müneccimbası* (head astronomer), replacing Yusūf ibn ˁUmar, and thus became well known as "Müneccimbası Muṣṭafā Čelebi." Upon his death in 1571, Muṣṭafā ibn ˁAlī was replaced by **Taqī al-Dīn**.

It is evident from the prefaces of his books that Muṣṭafā ibn ˁAlī began writing at a rather early age during his tenure as timekeeper of the Yavuz Sultan Selīm Mosque. One of his early works was *Iˁlām al-ˁibād fī aˁlām al-bilād* (in Turkish) on mathematical geography. Written in 1525, it was presented to Sultan Süleymān I and included astronomical and geographical information such as the distances to Istanbul (as the crow flies) of 100 major cities stretching from China to Morocco, their longitudes and latitudes, their *qibla*s (directions toward Mecca), and their shortest and longest days. It is clear from the introduction that the author regarded Istanbul as the center of the world, and that he chose cities that were along the lines of the Ottoman army conquest from Istanbul. Given that the book was presented to Sultan Süleymān, it could well be that it was produced for practical needs of the state. There are over 30 copies of the work in the Istanbul manuscript libraries, so it must have been widely read. (Süleymaniye Library, Hacı Mahmud MS 5633 is the author's copy.)

Muṣṭafā ibn ˁAlī's second work on geography, entitled *Tuḥfat al-zamān wa-kharīdat al-awān* (in Turkish), deals with cosmography, astronomy, and geography; a distinguishing feature of the work is its extensive application of mathematics to geography. Also written in 1525, it is clearly meant to complement his *Iˁlām al-ˁibād fī aˁlām al-bilād.* The Introduction provides general information about the science of geography and its sources. Chapter One offers detailed information about planetary orbs (*falak*s), planets, and stars; Chapter Two deals with the Earth, seas, islands, rivers, and mountains; Chapter Three takes up the seven climes as well as distances, longitudes, and latitudes of 150 cities within these seven climes; and Chapter Four discusses *zawāl* time. Muṣṭafā ibn ˁAlī relied on earlier Islamic works, namely **Jaghmīnī**'s *al-Mulakhkhaṣ fī ˁilm al-hay'a al-basīṭa* (An introduction to astronomy), **Qāḍīzāde al-Rūmī**'s commentary on Jaghmīnī's work, Damīrī's (died: 1405) para-zoological encyclopedia *Ḥayāt al-ḥayawān*, and Qazwīnī's (died: 1283) cosmological work *ˁAjā'ib al-makhlūqāt*.

The fact that Muṣṭafā ibn ˁAlī dedicated most of his important books to Sultan Süleymān and his grand viziers, and that he wrote almost all his works on astronomy and geography in Turkish rather than Arabic, indicate that he took the needs of the Ottoman state bureaucracy and society into account. A vast amount of the Graeco–Hellenic and Islamic astronomical corpus was transferred into Turkish. Indeed, Muṣṭafā ibn ˁAlī made a conscious effort to transform Turkish into a language of science. Out of his 24 astronomical works, 21 are in Turkish and the other three in Arabic. (See *OALT*, Vol. 1, pp. 177–179.) By writing in Turkish he was able to reach a greater audience (*i. e.,* beginning students of astronomy and timekeepers) as indicated by the number of extant manuscripts and late copies. Using Turkish was also an advantage when referring to Ottoman geographical locations, especially in Istanbul, the Balkans, and Anatolia.

Many of Muṣṭafā ibn ˁAlī's books deal with astronomical instruments. His *Faraḥ Fazā*, dedicated to Sultan Süleymān's Grand Vizier Ibrāhīm Pasha, examines the construction and use of the horary quadrant (*al-rubˁ al-āfāqī*) that he claims as his invention (Veliyüddîn Efendi MS 2282/3). Muṣṭafā ibn ˁAlī's *Kifāyat al-qanūˁ fī al-ˁamal bi-'l-rubˁ al-maqṭūˁ* (On the quadrant, in Arabic) clarifies and makes accessible the *Iẓhār al-sirr al-mawḍūˁ* by the famous astronomer-*muwaqqit* **Sibṭ al-Maridīnī** (died: 1506) who incorporated the traditions of Khalīlī and Ibn al-Shāṭir.

In 1529, Muṣṭafā ibn ˁAlī wrote *Kifāyat al-waqt li-maˁrifat al-dā'ir wa- faḍlihi wa-'l-samt* (in Turkish). Some 120 copies of the work, also known as *Risāla fī al-muqanṭarāt,* are extant; it deals with various aspects of geometry, trigonometry, and astronomy and also mentions an astronomical instrument called *rubˁ al-muqanṭarāt* (astrolabic quadrant). Muṣṭafā ibn ˁAlī's *Tas'hīl al-mīqāt*, written in 1529, discusses mathematical and astronomical features of timekeeping and specifically the usage of the astronomical instrument *al-rubˁ al-mujayyab* (sine quadrant). The book has five separate versions indicating that this work was updated. If we consider all five redactions as one work, there are presently about 100 copies that were widely used.

Another work written in 1529 is Muṣṭafā ibn ˁAlī's *Risālah-i jayb-i āfāqī* (in Turkish) in which he mentions the construction, usage, and mathematical properties of an astronomical instrument called *al-mujayyab al-āfāqi*. There are currently 50 known copies. His *Ḥall dā'irat muˁaddil al-nahār* (in Turkish), written in 1531 at the request of Grand Vizier Ayās Pasha, shows how to use this instrument according to the latitude of Istanbul (Nuruosmaniye MS 4891/4, author's copy). The *Risālat al-asṭurlāb al-Selīmī* (in Turkish), his most voluminous work, was written in 1544 and was based on the *Zīj* (astronomical handbook) of **Ulugh Beg**. In it, Muṣṭafā ibn ˁAlī examines the construction, mathematical properties, and usage of the astrolabe. His other works deal with various other instruments and aspects of timekeeping.

In his astronomical corpus, Muṣṭafā ibn ˁAlī al-Muwaqqit utilized a high level of geometry, trigonometry (especially spherical trigonometry), and numerical analysis; however, he writes in a simple language and presents easy and practical solutions. These features were instrumental in his textbooks and handbooks being used over many years in *Muwaqqithânes* (timekeeping institutions attached to mosques) and *madrasa*s (schools) throughout a wide geographical area.

İhsan Fazlıoğlu

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ˁAlī ibn ˁĪsā al-Asṭurlābī

Flourished **Damascus, (Syria), 832**

ˁAlī ibn ˁĪsā al-Asṭurlābī, author of an early Arabic treatise on the astrolabe and an opponent of astrology, enjoyed renown as an astronomical instrument maker and contributed to observations initiated by the ˁAbbāsid caliph **Ma'mūn**. He took part with **Khālid ibn ˁAbd al-Malik al-Marwarrūdhī** and others in an expedition to the Plain of Sinjār to measure 1° of latitude and, thus, the size of the Earth. ˁAlī ibn ˁĪsā made astronomical observations at Baghdad in 829/830 and at Damascus in 832–833. He divided the mural quadrant used for the Damascus observations to confirm results of the earlier missions.

Marvin Bolt

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ˁAlī ibn Khalaf: Abū al-Ḥasan ibn Aḥmar al-Ṣaydalānī

Flourished **Toledo, (Spain), 11th century**

ˁAlī ibn Khalaf is known for his work on "universal instruments." No details of his biography are known. In Arabic sources, he is only mentioned by **Ṣāˁid al-Andalusī** in his *Ṭabaqāt* as an outstanding geometer, who belonged, along with **Zarqālī**, to a group of young Toledan scholars interested in philosophy.

There are several variants of his name. A footnote in Bū ˁAlwān's edition of the *Ṭabaqāt* gives ˁAlī ibn Khalaf ibn Aḥmar Akhīr (or Akhiyar) al-Ṣaydalānī. A very similar reading quoted by an anonymous Egyptian 14th-century source (preserved in Leiden, Universiteitsbibliotheek, MS 468) is Abū al-Ḥasan ˁAlī ibn Khalaf ibn Akhir (or Akhyar) bearing the title al-Shajjārī, the botanist. This has led D. A. King to identify him with Abū al-Shajjār, who is mentioned in Zarqālī's treatise on the *ṣafīḥa zarqāliyya* (MS Escorial 962). King also identifies him with ˁAlī al-Shajjār, who appears in a list of astronomers in the *zīj* of **Ibn Isḥāq** (13th century; Hyderabad, Andhra Pradesh, MS 298). According to this source, ˁAlī ibn Khalaf determined a value of 77° 13′ 30 for the solar apogee, and he made an observation of the obliquity of the ecliptic of 23° 32′ 12″. This observation was made in Toledo in 1084/1085 with the aid of the physician, pharmacologist, and botanist Ibn Wāfid (died: 1075). Bearing in mind Ibn Wāfid's date of death, this may not be a completely reliable source.

ˁAlī ibn Khalaf is the author of a treatise on the use of the *lámina universal* (universal plate) preserved only in a Spanish translation included in the *Libros del Saber de Astronomía* (III, 11–132), compiled by the Spanish King **Alfonso X**. To our knowledge, the Arabic original is lost. ˁAlī ibn Khalaf is also credited with the construction of a universal instrument called *al-asṭurlāb al-ma'mūnī* in the year 1071, dedicated to al-Ma'mūn, ruler of Toledo.

The universal plate and the *ṣafīḥa* (the plate) of Zarqalī (devised in 1048) are the first "universal instruments" (*i. e.*, for all latitudes) developed in Andalus. Both are based on the stereographic meridian projection of each hemisphere, superimposing the projection of a half of the celestial sphere from the vernal point (and turning it) on to the projection of the other half from the autumnal point. However, their specific characteristics make them different instruments.

In ˁAlī ibn Khalaf's universal plate, the markings engraved on the mater correspond to longitudes and latitudes of ecliptic coordinates. The horizontal diameter represents the ecliptic, and the names of the zodiacal signs are engraved on the plate. These markings also can be used in a way corresponding to the almucantars and azimuthal circles of horizontal coordinates. The plate is fitted with a rete. One half of it shows a hollowed-out half-set of markings corresponding to the meridians and parallels of declination of equatorial coordinates; the other half shows a selection of star pointers from the Northern Hemisphere and the Southern Hemisphere. The rete is provided with two indexes. Although there is no evidence of examples of that instrument, its influence on the development of subsequent instruments has been suggested by E. Calvo.

Finally, in the introduction to his treatise, ˁAlī ibn Khalaf states his intention of writing a theoretical treatise on the several possibilities of projecting the sphere. However, there is no evidence of the existence of such a work.

Roser Puig

Alternate name

ˁAlī ibn Khalaf ibn Aḥmar Akhīr [Akhiyar]

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ˁAlī ibn Khalaf ibn Aḥmar Akhīr [Akhiyar]

➜ **ˁAlī ibn Khalaf: Abū al-Ḥasan ibn Aḥmar al-Ṣaydalānī**

Alighieri, Dante

Born **Florence, (Italy), May or June 1265**
Died **Ravenna, (Italy), 14 September 1321**

Dante Alighieri, a poet rather than an astronomer, is nevertheless remarkable for the extent to which he wove the astronomical conceptions of his day – principally Ptolemaic and Aristotelian – into the fabric of one of the greatest literary and imaginative works of the Middle Ages, his *Divina Commedia* (Divine Comedy).

Dante was the son of Alighiero di Bellincione Alighieri and his first wife, Bella. From youth to middle age Alighieri was involved in politics. However, at the turn of the century, the ruling party in Florence, the Guelphs, split into two factions, the "Blacks" and the "Whites," and with the victory of the Blacks, Alighieri, who was a White, went into permanent exile from his beloved native city. Because of his exile he was also permanently separated from his wife of some years, Gemma di Manetto Donati, with whom he had fathered four children, Jacopo, Pietro, Giovanni, and Antonia Beatrice. One of his consolations in exile was that Alighieri could still behold the stars as if he were in Florence.

Between 1306 and the end of his life, Alighieri composed his masterpiece, the *Divina Commedia* in three parts: the *Inferno* (or *Hell*), *Purgatory*, and *Paradise*. These parts comprise "cantos" (34, 33, and 33, respectively, for a perfect total of 100), which are in turn made up of interlocking stanzas of three lines that rhyme *aba*, *bcb*, *cdc*, and so on, a poetic form known as *terza rima*. The poem unfolds as a cosmically structured autobiographical narrative, each part representing a journey into, or up to, the realm indicated by its respective title. In the *Inferno*, Alighieri journeys downward from the surface of the Earth through the "circles" of hell until he reaches the dead center of Earth and of the Universe, where he finds Lucifer, not burning in fire but immobilized in ice, with both his head and his feet pointing upwards, though (logically, because he is at the center) in opposite directions. Carrying on past the center and upward into the Southern Hemisphere, Alighieri the narrator arrives at and climbs Mount Purgatory, achieving at its pinnacle a literal and figurative state of Edenic innocence, and so is prepared for the further ascent to Paradise. This final journey takes Alighieri up through the (Ptolemaic) spheres, or "wheels," of the planets to that of the fixed stars, and past it to the Primum Mobile, beyond which is the Empyrean. At this stage, however, as he looks still farther outward, Alighieri finds that in fact he is looking in. The Empyrean is thus conceived of as encompassing our universe, which in the allegory nevertheless emerges as peripheral to, and outside of, the Empyrean. Robert Osserman has suggested that, in this respect, Alighieri's idea of a numinous, singular point of light from which "hang the heavens and all nature" (*Paradiso*, 28) is consonant with the much later, initially counterintuitive but cosmologically significant non-Euclidean geometry that undergirds Big Bang cosmology.

Whether Alighieri was cosmologically original or not, the *Divinia Commedia* enriches one's understanding of the astronomy of the high Middle Ages, and an awareness of that astronomy in turn enriches one's reading of Alighieri's masterpiece. The poem's astronomical orientation is essential to both its narrative and its allegory, since the stars function as physical guides, spiritual inspiration, intellectual enrichment, and structural symbol. The first canto of each of its three parts establishes some astronomical reference. Even the gloomy first canto of the *Inferno* is brightened by morning,

and in his native sign
The Sun climbed with the stars whose glitterings
Attended on him when the Love Divine
First moved those happy, prime-created things.

Such moments of astronomical awareness recur at crucial moments throughout the *Divina Commedia*. The *Inferno*, *Purgatorio*, and *Paradiso* each conclude with the word *stelle* ("stars"). And the entire poem's final lines, echoing **Anicius Boëthius**'s hymn to Universal Love from the *Consolation of Philosophy*, fuse the order and divine orientation of both microcosm and macrocosm:

as a wheel moves smoothly, free from jars,
My will and my desire were turned by love,
The love that moves the sun and the other stars.

Dennis Danielson

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Allen, Clabon Walter

Born **Perth, Western Australia, Australia, 28 December 1904**
Died **Canberra, Australia, 10 December 1987**

Clabon Allen (normally C. W. Allen) is known to every practicing astronomer as the editor of the first three editions of *Allen's Astrophysical Quantities*. Indeed, so closely was his name tied to the concept that the fourth edition, prepared long after his death, is called *Allen's Astrophysical Quantities*, fourth edition, A. N. Cox, editor.

Allen was educated at the University of Western Australia, receiving a B.Sc. in 1925, and in 1926 was appointed as a Research Fellow at the newly founded Commonwealth Solar Observatory in Canberra (later the Mount Stromlo Observatory). Later, when he was awarded a Hackett Research Studentship for 2 years, the authorities would not grant him a 2-year leave. An act of the Australian Parliament was required to grant him leave, probably the only occasion when an astronomer's career required an act of Parliament to proceed.

Allen spent 1935/1936 in Cambridge University and 1936/1937 at Mount Wilson Observatory. His early work dealt with the spectrum of copper. He showed that some lines in the spectrum were anomalously broad. Their breadths did not depend on pressure; they were due to autoionization. This was the beginning of a lifelong interest in laboratory astrophysics. Allen wrote a thesis on the broadening of spectral lines for his M.Sc. in 1929.

After the solar telescope was completed in 1931, Allen started to work on the solar spectrum, measuring the strengths of a large number of spectral lines and constructing curves of growth. For this work his university conferred on him the D.Sc. in 1935.

At Mount Wilson Observatory, Allen worked on the atmospheric oxygen bands and on the central intensities of Fraunhofer lines. He went on five eclipse expeditions, only one of which (observing from South Africa in 1940) was completely successful. Results from that eclipse led him to the correct explanation of the presence of Fraunhofer lines in the coronal spectrum as due to scattering by interplanetary particles. In addition to war-related work at the Mount Wilson Observatory, Allen published important work on the relation between magnetic storms and solar activity.

In 1951 Allen moved to the University of London and became the first holder of the newly endowed Perren Professorship of Astronomy at University College and the director of the University of London Observatory. He reorganized the Astronomy Department in the college.

While in Canberra, Allen had started to collect numerical data from all branches of astronomy. In London he continued this work, and soon put his compilation into a book, *Astrophysical Quantities*, the first edition appearing in 1955 and the later editions in 1963 and 1973. He also started a program of work on laboratory astrophysics, chiefly the measurement of oscillator strengths. Allen retired in 1972 and returned to Australia.

The best known of Allen's Australian students was Colin S. Gum, who mapped the eponymous Gum Nebula (perhaps a very nearby supernova remnant). Of his London students, best known are infrared astronomer Vincent C. Reddish, (former Astronomer Royal for Scotland), Bruce Woodgate of the National Aeronautics and Space Administration's Goddard Space Flight Center, and solar astronomer Carole Jordan of Oxford University, who was the first woman to be elected president of the Royal Astronomical Society.

Roy H. Garstang

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Alhazen

➜ **Ibn al-Haytham: Abū ˁAlī al-Ḥasan ibn al-Ḥasan**

Aller, Lawrence Hugh

Born **Tacoma, Washington, USA, 24 September 1913**
Died **Malibu, California, USA, 16 March 2003**

American astronomer Lawrence Aller is known primarily for quantitative analysis of the spectra of stars and nebulae, leading to measurements of their chemical composition. He was among the first to recognize that the stars of **Walter Baade**'s Population II contain a much smaller share of heavy elements (beyond hydrogen and helium) than does the Sun and that different nova explosions eject different mixes of elements.

As the son of Leslie and Lella Belle (*née* Allen) Aller, Lawrence experienced a troubled childhood. His father moved the family from their hometown to San Francisco, California, where they stayed from 1922 to 1925. After a brief stay in Alaska in 1925, the family returned to Tacoma, where they lived until 1928, moving then to Seattle until 1931. Forced to work with his father and brother to support the family, Aller never graduated from high school. Somehow Aller found access to some Astronomical Society of the Pacific *Leaflets* that captured his imagination. Studying from a copy of the then comparatively new text *Astronomy* by **Henry Norris Russell**, **Raymond Dugan**, and **John Stewart**, Aller gained enough understanding of modern astrophysics to focus his career interests in that field. In a conversation with **Donald Menzel**, then at the Lick Observatory, Aller convinced Menzel that he had a thorough enough grounding and ample motivation to pursue astronomy at college level in spite of his lack of a high-school diploma.

After doing well in a few college astronomy course examinations, and with the recommendation of Menzel, Aller entered the University of California [UC] at Berkeley as a special student in 1932. He became a regular student there in the summer of 1932, and received a B.A. in 1936 with high honors. After completing many graduate courses, some of which provided the essential knowledge for his career (*e. g.*, astrophysics and quantum mechanics), he received his Master's degree in astronomy in 1937, and then went to Harvard University to pursue further graduate studies.

Aller was awarded the M.S. in 1938, and the Ph.D. in 1943, both from Harvard University. His doctoral thesis research, guided largely by Menzel, was based on the spectroscopy of planetary nebulae, using data taken at the Lick Observatory in 1938 and 1939. In 1939, Aller was elected as a Harvard Society Fellow, a position he held for 3 years.

In 1942, Aller became a physics instructor at Harvard University, for a year. He then worked at the UC Berkeley Radiation Laboratory from 1943 to 1945. He was an assistant professor of astronomy at Indiana University from 1945 to 1948. In 1948, Aller went to the University of Michigan as an associate professor of astronomy, and in 1954 he became a professor and stayed there until 1962. He moved to the University of California at Los Angeles [UCLA] in 1962, and was a professor there until his retirement as professor emeritus in 1985.

While in Cambridge, Aller married Rosalind Duncan Hall. The eldest of their three children, Hugh D. Aller, is a radio astronomer with an astronomer wife. The other son is a pathologist, and the daughter a civil engineer.

Aller's astronomical research career spanned over 60 years. During this time, he mentored many generations of students, now scattered around the world; he succeeded in inspiring them and helping them grow into successful astronomers and scientists in their own right.

Aller led a very interesting life, rich with experiences both in and out of the scientific arena. In particular, he recalled two memorable, if somewhat unfortunate, periods of his life. The first was when he was a young boy: He was forced by his father and elder brother to help with grueling, fruitless efforts in their search for gold. The second was the harsh criticism that he had endured while working at the Berkeley Radiation Laboratory. He felt ignored by his superiors there; in such a discouraging environment, it was no surprise that he once remarked: "The greatest threat is not a nuclear attack, but the mere existence of weapons themselves."

Aller's principal contribution to astronomy is in the area of chemical abundance studies of stars and gaseous nebulae. Elemental abundances give us important clues about the nuclear processes occurring at the final stages in the lives of stars like the Sun, the composition of the interstellar medium at the time when the progenitor star was formed, and the condensation of refractory elements onto solid dust grains in space. His efforts were directed mainly toward elemental abundances in the Sun and in gaseous nebulae. In particular, he concentrated on the so-called planetary nebulae; these are the ejecta from dying stars, which result when stellar cores contract to become white dwarfs, and their outer envelopes are blown off into the interstellar medium.

Aller, along with Menzel and **James Baker**, was the first to realize the possibility of obtaining nebular chemical compositions. Their pioneering work required the calculation of collision strengths and "A-values." Their work was published in a very long series of classic papers from 1937 to 1945, titled *Physical Processes in Gaseous Nebulae*. With W. Ufford and J. H. Van Vleck, Aller found that the [OII]3729/3726 line ratios in planetary nebulae are governed primarily by the electron density.

While teaching as an assistant professor at Indiana University, around 1946, Aller and David Bohm investigated the problem of the modification of the electron Maxwellian velocity distribution in the nebular plasma, due to the effects of inelastic collisions, recombinations, and bremsstrahlung radiation. They found that the Maxwellian distribution prevails even in the presence of these physical processes. Their new, quantitative analysis of this important astrophysical question yielded a physical solution that would prove essential for all later studies of gaseous nebulae.

Prior to this groundbreaking work, it was widely assumed that stellar spectra, in terms of the elemental abundances in stellar atmospheres, could be interpreted by the simple application of the well-known **Meghnad Saha** solution first derived in the 1920s. It was also commonly assumed, without any real justification, that chemical abundances in the observed object would be the same as those in the Sun. Aller was one of first pioneers to reject these unfounded assumptions, and in so doing he was the first to discover that there are indeed abundance differences among celestial objects. The currently used abundance determination methods remain essentially unchanged from those first proposed by him.

Aller's other notable works include the study of Wolf–Rayet stars, starting in the 1940s. He secured spectra using the Crossley telescope, and found excitation temperatures and ionic concentrations for both the N (nitrogen) and C (carbon) Wolf–Rayet sequences. He proposed the interpretation that the Wolf–Rayets are the remnants of massive, luminous stars.

During his sojourn in the University of Michigan, Aller undertook a quantitative analysis of high-dispersion spectra of the solar atmosphere. After taking up his UCLA professorship in 1962, he continued to work on problem, i.e., high-dispersion solar spectroscopy and solar abundance determinations, as well as Coude spectroscopy of B and A_p stars. He also obtained planetary nebula spectra with the prime-focus spectrograph and the Lallemand electronic camera on the Lick Observatory 3-m reflector.

In the spring of 1996, Aller had a paralyzing stroke, and had to be confined to a wheelchair. With what little remaining use he could make of his left hand, he was barely able to type. However, despite his handicap, he never stopped pursuing his research, and continued to investigate planetary nebulae with the help of his several coworkers. The honors he received included the 1992 Russell Lectureship of the American Astronomical Society.

Siek Hyung

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Alpetragius

➔ **Biṭrūjī: Nūr al-Dīn Abū Isḥāq [Abū Jaʿfar] Ibrāhīm ibn Yūsuf al-Biṭrūjī**

Alvarez, Luis Walter

Born **San Francisco, California, USA, 13 June 1911**
Died **Berkeley, California, USA, 1 September 1988**

American particle experimentalist Luis Alvarez is best known in the field of astronomy for work with his son, geophysicist Walter Alvarez that led to the idea that the wave of extinctions at the end of the Cretaceous Period, including the demise of the dinosaurs, was the result of an asteroid or comet impact. This was signified by an iridium-rich layer found at the Cretaceous–Tertiary boundary in a well-known deposit sequence at Gubbio, Italy.

Luis Alvarez was the son of physician Walter Alvarez, who continued to write down-to-earth columns of medical advice for the *Los Angeles Times* well into his 90s. The name had come directly from Spain a generation earlier.

Luis received his B.S. (1932) and Ph.D. (1936) from the University of Chicago, the latter for work in optics, and retained a lifelong research interest in ophthalmic optics. However, he simultaneously pursued, under the guidance of **Arthur Compton**, a project in which he adapted a Geiger counter for the study of secondary particles produced in the Earth's upper atmosphere by galactic cosmic ray impacts. He used the device to demonstrate, from a mountain top in Mexico, that the initial incoming particles must be primarily protons.

Alvarez joined the Radiation Laboratory of the University of California, Berkeley, as a research fellow in 1936, but was on leave at the Radiation Laboratory of the Massachusetts Institute of Technology [MIT] from 1940 to 1943, at the Metallurgical Laboratory of the University of Chicago in 1943/1944, and at the Los Alamos Laboratory of the Manhattan Project from 1944 to 1945. In 1937 Alvarez gave the first experimental demonstration of the existence of the phenomenon of *K*-electron capture by nuclei and a method for producing beams of very slow neutrons. This method subsequently led to a fundamental investigation of neutron scattering in *ortho*- and *para*-hydrogen (with Kenneth Pitzer) and to the first measurement of the magnetic moment of the neutron (with Felix Bloch). Along with Jake Wiens, Alvarez was responsible for the production of the first ^{198}Hg lamp; this device was developed by the United States National Bureau of Standards into its present form as the universal standard of length. Just before World War II, Alvarez and Robert Cornog discovered the radioactivity of ^{3}H (tritium) and showed that ^{3}He was a stable constituent of ordinary helium. Tritium is best known as a source of thermonuclear energy, and ^{3}He has become important in low-temperature research.

Alvarez also maintained a lifelong research interest in air navigation and was a skilled amateur pilot who could sometimes be persuaded to give a lecture at an out-of-the-way place if he had never flown into its airport before. He received the Collier Trophy (the US government's highest aviation award) for his contributions to radar and navigation.

During the war, while at MIT, Alvarez was responsible for developing important radar systems: the microwave early warning system, the Eagle high-altitude bombing system, and a blind landing system of civilian as well as military value. While at Los Alamos he developed the detonators for setting off the plutonium bomb. He also was responsible for the design and construction of the Berkeley 40-ft. proton linear accelerator, which was completed in 1947. In 1951 Alvarez published the first suggestion for charge exchange acceleration that quickly led to the development of the "Tandem Van de Graaf accelerator."

From that time on, Alvarez was engaged in high-energy physics, using the 6-billion electron volt Bevatron at the University of California Radiation Laboratory. His main efforts there were concentrated on the development and use of large liquid hydrogen bubble chambers, and on the development of high-speed devices to measure and analyze the millions of photographs produced each year by the bubble-chamber complex. The result of this work has been the discovery of a large number of previously unknown fundamental particle resonances by Alvarez' research group. It was for the bubble-chamber improvements and discovery of many resonances (which, in turn, led theorists to a coherent picture of proton and neutron structure that fit into the scheme of particles in general) that he received the 1968 Nobel Prize in Physics.

In 1955, Alvarez organized an expedition to use cosmic ray secondaries (muons) to look for previously unknown chambers in the pyramid of Khufu (Cheops). The point is that the muons reach the ground with enough energy to penetrate a fair amount of rock. Therefore, they put detectors in the known chambers and recorded the rate of muon arrival as a function of direction, looking for angles where more muons might get through than expected, implying additional chambers in the pyramid. None were found.

Alvarez shared his last major scientific achievement with his son Walter, who was then a professor of geology at Berkeley. They accidentally discovered a band of sedimentary rock in Italy that contained an unusually high level of the rare metal iridium. Dating techniques set the age of the layer at about 65 million years. The two hypothesized that the iridium came from an asteroid that struck the Earth, thereby sending huge volumes of smoke and dust (including the iridium) into the Earth's atmosphere. They suggested that the cloud covered the planet for an extended period of time, blocked out sunlight, and caused the widespread death of plant life on Earth's surface. The loss of plant life brought about the extinction of dinosaurs that fed on the plants. An impact origin for the major extinction episode at the end of the Cretaceous is generally accepted, though its interaction with other mechanisms remains under debate, as does the implication for possible similar effects ("nuclear winter") of extended nuclear warfare.

Alvarez served on the President's Science Advisory Committee (1971/1972) and as the president of the American Physical Society (1969). He received the National Medal of Science, the Einstein Medal, and about half a dozen honorary D.Sc.'s.

Fathi Habashi

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Amājūr Family

Flourished **late 9th/early 10th century**

The Amājūr Family includes Abū al-Qāsim ʿAbd Allāh ibn Amājūr al-Turkī al-Harawī, his son Abū al-Ḥasan ʿAlī, a certain ʿAlī ʿAbd Allāh ibn Amājūr, and Abū al- Ḥasan's freed slave Mufliḥ ibn Yūsuf. They are known for their extensive observational astronomical work, and for compiling the results of these observations into several *zīj*es (astronomical handbooks). It is said that they were assisted in their observations by a large group of people.

There is little information about the Amājūr Family's lives in either historical or modern sources. There is also some ambiguity about their names and identities. **Ibn Yūnus** refers to the father as al-Turkī and mentions another person as having assisted him in doing the astronomical observations along with his son and his slave. Ibn al-Qifṭī, though, refers to Abū al-Qāsim as al-Ḥarawī from the city of Herat; he informs us that the son Abū al-Ḥasan ʿAlī was raised by his father, who had educated him in the sciences. Ibn al-Qifṭī considers ʿAlī ibn Amājūr as a separate person, and not necessarily related to Abū al-Qāsim. Both Ibn al-Nadīm and Ibn al-Qifṭī believe that the family hailed from Farghāna.

The Amājūr Family carried out their astronomical observations between 885 and 933; most of their work took place in Baghdad and, to a lesser extent, in Shīrāz. Their long-term astronomical observations, which lasted 30–50 years, involved work on the fixed stars, the Sun, the Moon, and the planets. There has been speculation that there was an observatory of some sort in connection with the Amājūr Family based on their needs for precise observations and for recording their results. There is also a report that a large group aided the Amājūr Family with their observations. Ibn Yūnus, who records observations of solar and lunar eclipses and planetary positions by the Amājūr Family, indicates that they carried out their observations at a raised, flat place with a view, called a "ṭārum" or "ṭāruma." On the basis of his research, Caussin concludes that there was an observatory.

There is little information regarding the instruments that were used by the Amājūr Family. However, ʿAbd Allāh ibn Amājūr mentions one he used to observe a solar eclipse on 18 August 928 with Abū al-Ḥasan and Mufliḥ. From the information provided on this observation, Caussin determined that the instrument had to be quite large given the preciseness of the measurements.

ʿAbd Allāh ibn Amājūr was apparently well known in his time, and he wrote a number of books, most of them *zīj*es. According to D. King, ʿAlī ibn Amājūr worked on improving **Khwārizmī**'s (9th century) prayer tables, providing the approximate times for different latitudes.

ˁAlī ibn Amājūr also prepared a prayer table for Baghdad, based upon precise trigonometrical calculations.

İhsan Fazlıoğlu

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Ambartsumian, Victor Amazaspovitch

Born **Tbilisi, (Georgia), 18 September 1908**
Died **Byurakan, Armenia, 12 August 1996**

Victor Ambartsumian formulated ideas pertinent to the structure and evolution of stars, of galaxies – especially active ones – and of the entire Universe. Some of these ideas, for instance the unboundedness of many star clusters and the need for star formation to be an ongoing process, have stood the test of time. Others have not.

Victor was the son of Amazasp Asaturovich Ambartsumian, a historian (and, later in life, professor at Yerevan University), and Ripsame Ambartsumian. He married Vera, the adopted daughter of **Grigory Shain**, the then director of the Crimean Observatory. Victor and Vera had two daughters and two sons.

Ambartsumian's elementary and secondary schooling took place in Tbilisi, Georgia. He graduated from the University of Leningrad, Russia in 1928. Ambartsumian was a staff member of the Pulkovo Observatory (near Leningrad, now Saint Petersburg, Russia) from 1928 to 1931. In 1931 he became a lecturer, and in 1934 a professor, at the Leningrad University. In 1943 Ambartsumian founded, and from 1944–1988 was director of the Byurakan Observatory, Armenia. In 1947 he was appointed professor of astrophysics at the University of Yerevan, Armenia.

Ambartsumian was the president of the Armenian Academy of Sciences from 1947 to 1993. In 1953, he became a member, and in 1961 a member of the presidium, of the Academy of Sciences of the Soviet Union. Ambartsumian held numerous foreign memberships of academies, among which were the Royal Society, the United States National Academy of Sciences, the Indian Academy of Sciences, and the Royal Netherlands Academy of Sciences. He was a recipient of the Gold Medal of the Royal Astronomical Society in 1960 and the Bruce Medal of the Astronomical Society of the Pacific, also in 1960. In 1971 Ambartsumian received the Helmholtz Medal of the East German Academy of Sciences.

In 1965, Ambartsumian founded the journal *Astrofizika*, in Russian, with its English translation *Astrophysics.*

In a 1929 paper, Ambartsumian studied the problem: to what degree do the eigenfunctions of an ordinary differential operator determine the functions and parameters entering into that operator? Fifteen years later (1944) this paper attracted the attention of mathematicians in the context of the theory of inverse problems.

Ambartsumian's earliest astrophysical work was in solar physics, in collaboration with **Nikolai Kozyrev**, and in the physics of emission nebulae and radiation transfer, starting from **Herman Zanstra**'s papers in this field. Ambartsumian applied this work to the planetary nebulae and to the so-called Wolf–Rayet stars, both being cases of interaction between a star and its gaseous envelope. This effort led to Ambartsumian's prediction of the existence of a forbidden He line in the spectra of Wolf–Rayet stars, which later was identified. In 1939 he published a comprehensive book on astrophysics, a more extended version of which was published in 1952 in collaboration with E. R. Mustel, A. B. L. Severny, and V. V. Sobolev under the title *Theoretical Astrophysics*.

Studies of the brightness distribution of the Milky Way, in particular the correlation of the brightness in two different directions, led Ambartsumian to estimates of the properties of interstellar clouds. Although it is obvious both from photographs of emission nebulae and dark clouds and from radio-astronomical surveys that description of the structure of the interstellar medium [ISM] in terms of discrete clouds is an oversimplification, this concept has proven to be very helpful in describing the ISM. Ambartsumian's estimates of the dimensions and optical depth of these clouds, and his studies of the relation between the clouds and the exciting, luminous stars belong to the early pioneering steps in this domain.

By the end of the 1930s, Ambartsumian's interest shifted to problems of stellar evolution and to the still more fundamental question of the formation process of the stars. Early work on stellar dynamics had convinced him that wide double stars, contrary to the prevailing view, could not have existed over a timescale (the "long" timescale proposed by **James Jeans**) very much longer than 10 billion years. He now concentrated on the birth and evolution of small, compact clusters (and the rate of evaporation of their member stars) and of the much larger, very loose groups of stars for which he introduced the term "stellar associations." Although the existence of the latter had been long known, Ambartsumian stressed the fact that, due to the gravitational field of the Galaxy, these associations would disperse relatively rapidly among the general galactic stellar population and, hence, could not have existed over a time-span comparable to the age of the Galaxy (in fact, not even longer than tens to hundreds of millions of years). The inference was that the stellar associations must have been born very recently on the galactic timescale and star formation must still be an ongoing process in the Galaxy. This unorthodox view found support from various sides, including studies of the source of stellar (nuclear) energy and the study of the relative motions of the stars in the associations. To a considerable extent, he and his staff devoted the facilities of Byurakan Observatory to research on stellar associations and extragalactic systems.

With regard to the origin of the associations, Ambartsumian also took an unorthodox view. He postulated that stars were formed from superdense bodies, a hitherto unknown state of matter, which was contrary to the general belief that star formation was preceded by gradual contraction in an interstellar gas cloud. He identified the very young, compact groups, for which he introduced the name trapezium systems (in analogy with the well-known compact cluster in Orion), with the earliest emergence from this primordial matter. This view, however, has not found general acceptance; subsequent developments fully confirm the classic view that star formation follows contraction in the interstellar medium. Ambartsumian also postulated an origin from this superdense matter in the case of stellar systems as a whole, referring to the violent processes observed in the central regions of certain galaxies. Here, too, his concept has not found confirmation. However, the extensive surveys of quasars and active galaxies carried out at Byurakan Observatory by his associates, in the context of Ambartsumian's ideas (in particular by **Beniamin Markarian**), have contributed greatly to our knowledge of extragalactic systems.

Ambartsumian played a prominent role in the international relations of Soviet science, in particular in the domain of astronomy. When, shortly after the termination of World War II, the International Astronomical Union [IAU] resumed its activities at the Zürich (Switzerland) General Assembly in 1948, Ambartsumian became one of the vice presidents (for the years 1948–1955) of the newly elected Executive Committee. During the years 1961–1964 he was its president. From 1968 to 1972 he was the president of the International Council of Scientific Unions [ICSU].

In 1940, Ambartsumian became a member of the Communist Party of the Soviet Union and, in 1950, Deputy to the Supreme Soviet on behalf of the Republic of Armenia. He received many awards of the Soviet Union, including the Hammer and Sickle Gold Medal, five orders of Lenin, and the Stalin Prize. He was twice Hero of Soviet Labor. He was awarded the medal of a National Hero of Armenia. As is evident from these honors, his political views harmonized to a considerable degree with those of Soviet rulers. Involvement, early in his career, of Ambartsumian and some young collaborators in a conflict with the director of Pulkovo Observatory, **Boris Gerasimovich** (which coincided with the years of Stalin's purges) led to their alienation from the observatory and to the imprisonment of Gerasimovich, who was executed in 1937, along with several other members of the Pulkova staff. During Ambartsumian's vice presidency of the IAU his political position and his diplomacy were severely tried. At the invitation of the Soviet Academy of Sciences – an invitation extended by Ambartsumian himself – the 1951 General Assembly of the IAU was to be held in Leningrad, an invitation prompted by the inauguration of the rebuilt Pulkovo Observatory (which had been destroyed in the siege of Leningrad). However, half a year before the assembly, the IAU Executive Committee felt obliged to cancel the assembly in view of rapidly increasing international tensions, the "Cold War." This decision caused deep disappointment and incomprehension among the astronomical community of the Soviet Union and its political allies, so much that even their withdrawal from the IAU was feared. Only in 1958 did the IAU meet in the Soviet Union, in Moscow. During these years, Ambartsumian, although violently opposing the IAU's policy, remained loyal to the Executive Committee's majority decisions for the sake of safeguarding international collaboration, an attitude that contributed to his election as President of the IAU in 1961.

Adriaan Blaauw

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Amici, Giovanni Battista

Born **Modena, (Italy), 25 March 1786**
Died **Florence, Italy, 10 April 1863**

Giovanni Amici was an expert in optics as well as a very talented maker and user of lenses, objectives, prisms, and optical instruments.

After obtaining a degree in engineering, Amici became professor (from 1815) at Modena University. Here he began his studies in astronomy, making observations of the Sun, comets, Jupiter, and Saturn. In 1831 the Grand Duke of Tuscany, Leopoldo II, appointed him as director of Florence's observatory.

Amici's prism is quoted in every book on optics, and **Giovan Donati** was able to discover **Joseph von Fraunhofer**'s lines in stellar spectra by using a spectroscope suggested by Amici. Amici was also a great botanist.

Mariafortuna Pietroluongo

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ˁĀmilī: Bahā' al-Dīn Muḥammad ibn Ḥusayn al-ˁĀmilī

Born **Baˁlabakk near Jabal al-ˁĀmilī, (Lebanon), 18 February 1547**
Died **Isfahan, Iran, 1 September 1621**

Bahā' al-Dīn Muḥammad ibn Ḥusayn al-ˁĀmilī, better known in Iran as Shaykh-i Bahā'ī, was probably the last scholar in the chain of universal and encyclopedic scholars that Islamic civilization was still producing as late as the 16th century. A major figure in the cultural revival of Safavid Iran, he wrote numerous works on astronomy, mathematics, and religious sciences and was one of the very few in the Islamic world to have propounded the possibility of the Earth's movement prior to the spread of Copernican discoveries in astronomy.

Bahā'ī's family came from the village of Jubaˁ near the coastal town of Sidon in southern Lebanon, in the vicinity of Jabal ˁāmil, whence his name. He was still a young boy when his whole family, as part of a wave of Shīˁa scholars, migrated to Iran to escape the persecutions of the Shiite Muslims by the Ottomans.

Bahā'ī's father, a prominent scholar with an impressive reputation, was well received in the court of the Safavid monarch Shah Ṭahmāsb, assuming the office of chief jurisconsult in the Safavid administration. Bahā'ī's father takes the credit for Bahā'ī's early education, by virtue of which he mastered the religious sciences. He further studied logic, philosophy, mathematics, and astronomy under the most prominent scholars of the day, excelling in these sciences as well.

Bahā'ī soon rose to prominence in the Safavid court and was appointed to the office of chief jurisconsult in the court of Shāh ˁAbbās the Great. Nevertheless, court engagements and public duties never seem to have deterred him from his scholarly activities, both as a teacher and as a writer. He trained many students, some of whom became the most prominent scholars of the period.

Bahā'ī may be counted among the most prolific writers of Islamic civilization, having written more than 100 treatises and books. His works cover a wide range of subjects, from religious sciences to mathematics, astronomy, and the occult sciences. In addition to these, he wrote a literary-religio-scientific anthology known as *Kashkūl*, which, apart from its literary and scientific merits, is of utmost importance in understanding the man and his thoughts. Bahā'ī's *Khulāṣat al-ḥisāb* (Essentials of arithmetic), was to become the most popular textbook throughout the Islamic lands from Egypt to India until the 19th century. This book was translated into German by G. H. F. Nesselmann and published in Berlin as early as 1843; a French translation appeared in 1854.

Our sources do not provide a definitive list of Bahā'ī's astronomical works. However, he seems to have written as many as 17 tracts and books on astronomy and related subjects, including a number of glosses and commentaries on the works of past masters. He also wrote *Risālah dar ḥall-i ishkāl-i ˁuṭārid wa qamar* (Treatise on the problems of the Moon and Mercury), in an attempt to find solutions to the inconsistencies of the Ptolemaic system within the context of Islamic astronomy. In his summary of theoretical astronomy entitled *Tashrīḥ al-aflāk* (Anatomy of the celestial spheres), he upholds the view of the positional rotation of the Earth, arguing that no sufficient proof has been offered so far to the contrary. In expressing this view, Bahā'ī stands out as one of the very few Muslim scholars to have advocated the feasibility of the Earth's rotation as early as the 16th century, this independent of Western influences.

Since no serious study of Bahā'ī's scientific works (especially those related to astronomical fields) has been made so far, one cannot make a critical assessment of his achievements and contributions in this area. Yet his works clearly demonstrate the fact that he was a scholar with a critical and disciplined mind. Furthermore, Bahā'ī's works demonstrate the clarity and discipline of a mathematician's mind that is able to present scientific issues in a simple and easy-to-understand manner.

A number of architectural and engineering works have been attributed to Bahā'ī as well, though none can be substantiated by the sources. He is credited with the distribution of the waters of the Zayandeh-Rud River through a complex network of irrigation canals, based on a distribution map known as Bahā'ī's scroll. Furthermore, according to a popular legend he engineered a heating system for a public bath in Isfahan that drew all the energy needed for heating the water and the bath itself from a single candle!

In addition to his many-faceted scientific capabilities, Bahā'ī was a gifted poet and has bequeathed some very fine pieces of poetry, mostly with mystical themes, which are still cherished by the public. Some of Bahā'ī's works, particularly the *Kashkūl,* demonstrate very strong mystical tendencies of the author. He spent part of his life traveling in Ottoman territories, which brought him into close contact with prominent scholars of his time in Aleppo, Damascus, Jerusalem, Cairo, and elsewhere. Brief reports of some of these meetings and exchanges have been recorded in his *Kashūkl.*

Bahā'ī was also famed for his works of charity, which had turned his home into a shelter and refuge for orphans, widows, and the needy. Bahā'ī has remained a very popular figure in public memory, and many anecdotes about him have passed from generation to generation, some even attributing miraculous acts to him. Bahā'ī died in Isfahan and his body was carried to Mashhad (in northeast Iran) to be laid to rest in the shrine of Shiˁism's eighth *īmām*, ˁAlī ibn Mūsā.

Behnaz Hashemipour

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Ammonius

Born **probably Alexandria, (Egypt), *circa* 440**
Died **Alexandria, (Egypt), *circa* 521**

Neoplatonist Ammonius was the son of Hermeias (the scholarch of the Alexandrian school) and Aidesia (admired for her prudence and piety, "the most beautiful woman in Alexandria," and a close relative of Surianus , scholarch of the Athenian Academy from 431 to 437). His younger and less studious brother **Heliodorus** was also a philosopher, while his paternal uncle Gregorius was an astronomer.

Ammonius was born under the learned emperor and legal codifier Theodosius II, and was an adolescent when Rome fell to the Vandal army. He studied philosophy at the academy in Athens for many years from about 460 under **Proclus** of Lydia (scholarch there from 437 to 485), among whose students Ammonius is said to have excelled in mathematics and astronomy. He then succeeded his father as scholarch in Alexandria in 485, a post he held, through a time of religious strife and political regionalism, until his death.

Ammonius's students include many productive philosophers: Asklepius of Tralles, Damaskius, Gesius, **Olympiodorus**, **Ioannes Philoponus**, **Simplicius**, Theodotus, and Bishop Zacharias of Mytilene. His own publications appeared between 485 and 510, though much of what Philoponus published thereafter contains Ammonian material. (His name refers to the god and oracle Ammôn at Siwa in the Egyptian desert; the native form is "Amun," the chief god of Thebes and of Egypt generally.)

Ammonius wrote Neoplatonic philosophy; in his era this meant primarily commentaries on **Plato** and **Aristotle**, which had the goal of demonstrating the essential unity and harmony of their thought. (Ammonius also wrote on grammar, rhetoric, mathematics, and astronomy.) Most of his work is lost or survives only in extracts.

Among Ammonius's known astronomical contributions is his denial of determinism (*i. e.*, astrology). He argued that gods know all of time, but that such knowledge does not constrain future events: they have knowledge of future contingents, but not as future (an idea derived from Iamblichus' suggestion that the divine knowledge is definite but is about indefinites). Ammonius is attested to have made observations (with his brother and his uncle) of planetary occultations or near conjunctions, as well as of the longitude of Arcturus (with Simplicius), the latter to check **Ptolemy**'s value of the precession of the equinoxes (which Ammonius erroneously confirmed). On this basis, he conjectured (or caused Simplicius to conjecture) that outside the geocentric sphere of the fixed stars, there was a further starless sphere, the eternal "prime mover" of the *kosmos*. Finally, and coupled therewith, Ammonius argued on teleological grounds for the eternity of the *kosmos* (as had Aristotle), and interpreted Plato's *Timaeus* as teaching an eternal *kosmos* (a doctrine contradicting the dominant theology of the Christians, despite his attested accommodation with Archbishop Athanasius). Recently, Ammonius's work on the use of the astrolabe has been rediscovered and published (though no English translation exists).

Paul T. Keyser

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Anaxagoras of Clazomenae

Born **(Greece), 500 BCE**
Died **(Greece), 428 BCE**

The dates for Greek cosmologist Anaxagoras' birth and death come from Diogenes Laertius, a Greek biographer of the 3rd century, famous for his 10-volume *Lives of Eminent Philosophers*. Anaxagoras was "said to have been 20 years old at the time of Xerxes' crossing (the Persian king led an army into Greece in 480 BCE) and to have lived to 72." Diogenes also cited **Apollodorus**, an Alexandrian chronographer of the 2nd century who wrote in his *Chronicles* that Anaxagoras "was born in the 17th Olympiad and died in the first year of the 88th." (The first year of the first Olympiad was 776 BCE; each Olympiad lasted 4 years.)

A major problem for ancient philosophers was how to explain change – how there could be coming-to-be and passing away. Philosophers argued for varying numbers and types of elements that, combining in different proportions, accounted for all known substances. For **Thales**, water was the basic matter or principal of things; for **Anaximenes**, it was air; for **Heraclitus**, fire; for **Xenophanes**, everything was composed of water and earth; and for **Empedocles**, there were four primary elements: earth, water, air, and fire. Anaxagoras seems to have argued that no natural substance was more elemental than any other, that every kind of natural substance existed together in the primordial mixture when everything was together, and that every type of natural substance now existed in every object. His speculations were preserved by the commentator **Simplicius**, writing in Athens in the 6th century: "All things were together, infinite in respect of both number and smallness … all things are in the whole … nothing comes into being nor perishes, but is rather compounded or dissolved from things that are." Early Greek philosophers instituted the practice of rational criticism and debate by tackling the same problems, investigating the same natural phenomena, and confronting their opponents' theories. But unlike modern scientific research, their speculations were largely devoid of experimental confirmation.

Anaxagoras is sometimes cited as an early victim of the conflict between science and religion. His new theory of universal order collided with popular faith – the belief that gods ruled the celestial phenomena – and he was expelled from Athens. The indictment against him, however, included the accusation of corresponding with agents of Persia, and impiety might have been an incidental charge. The conflict between science and religion, though accurately characterizing later ages, is not necessarily applicable to the ancient world.

Historians of astronomy also have tended to make their subject a chronology of accumulating positive achievement, emphasizing ancient speculations and observations later validated as scientific by modern standards. The correct explanation of eclipses is often credited to Anaxagoras. The source for the attribution is Hippolytus, a theologian in Rome in the 3rd century, who attempted to refute Christian heresies by showing them to be revivals of pagan philosophy. Seemingly, Anaxagoras believed that "the Sun, the Moon, and all the stars are red-hot stones which the rotation of the aether carries round with it," yet "the Moon has not any light of its own but derives it from the Sun …. Eclipses of the Moon are due to its being screened by the Earth, or, sometimes, by the bodies beneath the Moon; those of the Sun to screening by the Moon when it is new."

According to Diogenes Laertius, Anaxagoras predicted the fall of a meteorite: "They say that he foretold the fall of the stone at Aegospotami, saying that it would fall from the Sun." Perhaps this large meteorite, which fell in 467 BCE, led to his belief that the Sun, the Moon, and the stars were red-hot stones.

Norriss Hetherington

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Anaximander of Miletus

Born **Miletus (near Söke, Turkey) *circa* 611 BCE**

Anaximander of Miletus is generally regarded as the second philosopher in the western philosophical tradition after **Thales**. He was the son of Praxiades. Miletus was a commercial city on the coast of Ionia (part of present-day Turkey).

Details of Anaximander's life are lacking, though it seems certain that he was the first to write a treatise on nature. Only a single fragment of this work remains, in which he announced that the "boundless" or "indefinite" is the first principle or primal "stuff" from which all things originate. Still, his theories are widely attested in the doxography, allowing a general picture of his cosmology.

Departing from the Homeric view that the Earth was a flat plate or disk, Anaximander characterized it as a drum-shaped cylinder suspended in midair. This placement strongly suggested that the heavenly bodies passed through the sky and then under the Earth to reappear again the next day, thereby superseding earlier cosmological tendencies that limited the movement of heavenly bodies only to the sky above. On one surface of the drum was the inhabited world. On the other was another world, though there is some question about whether Anaximander thought it was inhabited as well.

The diameter of the Earth was three times its height. Circling the Earth were rings of fire encased in mist, with apertures through which the fire would shine, thereby explaining the heavenly bodies. The ring of the Sun was 27 times the diameter of the Earth, and that of the Moon was 18. There was a separate ring for each of the stars and planets, inclined at various angles, each located closer to the Earth than the Moon, unlike the views of later Greek cosmologists. Because of a lacuna in the ancient sources, we do not know the precise size of these rings, though Anaximander's mathematical method would seem to suggest that they were nine times the diameter of the Earth. Anaximander accounted for eclipses and the phases of the Moon by hypothesizing that the apertures in the pertinent rings would expand and contract.

According to ancient tradition, Anaximander introduced the gnomon, or sundial, into Greece, and used it to mark the hours and seasons, along with the solstices and equinoxes. Consequently, he is generally credited with discovering the obliquity of the zodiac, most likely accounting for its north/south wobble by an appeal to wind. Anaximander is also reputed to have been the first to draw a map of the inhabited world. Most surprising, perhaps, in Anaximander's cosmology, is the view that there are innumerable worlds or other *kosmoi*, though scholars disagree on whether the theory held that these worlds coexisted in space or whether they existed only in temporal succession.

Anthony F. Beavers

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Anaximenes of Miletus

Born **Miletus (near Söke, Turkey), *circa* 586 BCE**
Died **Miletus (near Söke, Turkey), *circa* 526 BCE**

Anaximenes was a fellow citizen, friend, and student of **Anaximander**, and much of his thought is a revision of Anaximander's. Some aspects of his physical theory, notably his use of empirical models and his attempt to identify a cause of elemental change, constitute scientific advances, but his astronomical views are less original and more traditional than those of his predecessor.

Nothing is known of the details of Anaximenes' life. Even the dates given above are highly conjectural. They derive from **Apollodorus**, who liked to correlate historical figures' flourishing, invariably at the age of 40, with some notable historical event. In Anaximenes' case, the event was Cyrus' victory over Croesus in 546 BCE.

Anaximander had hypothesized that the infinite space beyond the visible cosmos is filled with undifferentiated, indeterminate stuff (*apeiron*), from which the determinate kinds of matter we perceive are spun off. Anaximenes, seeing no need to postulate an imperceptible form of matter, proposed instead that air is infinite. Although this idea probably arose from the fact that atmospheric air has no readily discernible boundaries, Anaximenes extended the sense of air's infinity. Those parts of space occupied by fire, liquids, or solids are really filled with air, these being air of nonstandard density. Fire is rarefied air; "wind, then cloud, … water, then earth, then stones" are progressively denser forms of air. This theory of rarefaction and condensation is the first recorded attempt to explain material differences by a single mechanism. Air is not an inert material but is "divine" or "a god" – an active agency holding the Universe together analogously to the way souls, conceived following the ancient notion of the "breath of life," unify living organisms.

Anaximenes modified Anaximander's astronomical views to fit his physics. Anaximander supposed the Earth to be a columnar body maintaining its central location in the cosmos because it is at the center of mass and so has no tendency to move in any direction, whereas Anaximenes postulated a thinner, table-shaped Earth, supported pneumatically. The air beneath the Earth supports it because of Earth's flat shape. Aristotle thought his point was that the Earth functioned as a lid and commented that size, rather than shape, should have been the relevant condition, since air can only support objects, of whatever shape, which do not permit the air to leak past them. However, if the air is infinite it could not be contained as **Aristotle** presumed; so, perhaps Anaximenes' idea was that Earth's flatness enables it to float on the air or even that infinite free fall would be indistinguishable from rest.

For reasons unknown, Anaximenes took Earth to be an early condensate from air, and visible celestial objects to be end products of sublimation or evaporation from the Earth. He believed the incandescent objects consisted of fire, but he also posited invisible earthy companions orbiting along with them. Some have supposed these to be part of a theory of eclipses, but more likely their purpose was to explain meteorites.

The Sun rides on the atmosphere because it is "flat, like a leaf" (Aetius II, 22, 1). Aetius reports that some say the stars too are leaf-like, but in the same passage he writes that Anaximenes said they were like nails embedded in a transparent shell. Some scholars harmonize these conflicting claims by suggesting that Anaximenes may have been the first to distinguish between planets and fixed stars, the former floating "leaf-like" and the latter being stuck in a crystalline, or membrane-like, dome.

For Anaximenes, the sky really was a dome, not a sphere; celestial bodies do not pass under the Earth but revolve around it, as a felt cap might be turned on one's head. The diurnal setting of astronomical objects is not explained by their rotating through antipodean positions, but by a shallower rotation that carries them further from us until they eventually disappear behind more elevated parts of the Earth to the north. Perhaps he had heard of northern lands where the summer Sun did not set. Presumably, annual declinational changes would have been explained as rhythmically alternating northerly and southerly tilting of the celestial "cap."

James Dye

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Andalò di Negro of Genoa

Died **1342**

Andalò di Negro wrote on the distances and magnitudes of the planets.

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Anderson, Carl David

Born **New York, New York, USA, 3 September 1905**
Died **San Marino, California, USA, 11 January 1991**

American cosmic-ray physicist Carl Anderson is best known for the discovery of the positron (a particle with the same mass as the electron but positively charged) for which he shared the 1936 Nobel Prize in Physics, with **Viktor Hess**, who was recognized for the discovery of cosmic rays.

Anderson was the child of Swedish immigrants Carl David Anderson and Emma Adolfina Ajaxon. He married Lorraine Bergman in 1946, and they had two children. Anderson spent his entire professional career at the California Institute of Technology, receiving a B.S. (1927) and a Ph.D. in physics (1930), the latter for work with **Robert Millikan** on particle detectors. He was appointed a research fellow for the period 1930–1933, becoming assistant professor of physics in 1933, then associate professor, and being promoted to full professor in 1939, only after he had won the Nobel Prize. Anderson's work during World War II was under the auspices of the National Defense Research Council and the Office of Scientific Research and Development (1941–1945). He chaired the division of physics, mathematics, and astronomy at Caltech from 1962 to 1970, and received honorary degrees from Colgate University, Gustavus Adolphus University, and Temple University, and other major awards from the Franklin Institute and the American Society of Swedish Engineers.

Anderson described his own research interests as X-rays, gamma rays, radioactivity, and cosmic rays, but is best known for the last of these, beginning with the study of cosmic-ray secondary particles using cloud-chamber photographs obtained from balloons. In 1933 he concluded that positively charged particles, which he had originally identified as protons, must have the mass of an electron. The new particle, which Anderson called a positron, was soon confirmed by other physicists and identified with the antielectron predicted by Paul Dirac in 1931. In 1937 Anderson, together with Seth Neddermeyer, studied highly penetrating particles in the cosmic radiation and suggested the existence of yet another elementary particle, the mesotron or meson, now called the muon or μ meson. This new particle was initially mistaken for the carrier of the nuclear force, which was later also found in cosmic-ray showers and has about the same mass (called the pion or π meson), but otherwise very different properties. Instead, the muon proved to be the very first member of two whole new families of particles (including multiple kinds of quarks, neutrinos, and other leptons), just as the positron proved to be the first antimatter particle recognized by physicists. Anderson thus, in effect, enormously expanded the repertoire of fundamental particles to be found in the Universe.

Helge Kragh

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Anderson, John August

Born **Rollag, Minnesota, USA, 7 August 1876**
Died **Altadena, California, USA, 2 December 1959**

American spectroscopist John Anderson made important contributions to astronomy by ruling excellent gratings for spectrographs, developing techniques to study gases at stellar temperatures, and supervising the production and testing of optical components for the 200-in. telescope on Palomar Mountain. Anderson was the son of Norwegian immigrants and was educated at Concordia College, the State Normal School in Moorhead, Minnesota, and Valparaiso College, Indiana (B.S.: 1900), interrupted by periods working in a hardware store and at a lumberyard. He taught physics and other subjects in Clay County, Minnesota, before beginning graduate studies at Johns Hopkins University, where he received his Ph.D. in 1907 with a thesis on the absorption and emission spectra of compounds of neodymium and erbium. In 1908, Anderson worked on absorption spectra of solutions with Harry C. Jones (physical chemistry) at John Hopkins University, participated in a United States Naval Observatory eclipse expedition to Spain, and spent the summer at the University of Virginia, attempting to measure the interaction of plane-polarized light with tourmaline crystals (which are birefringent).

Anderson returned to Johns Hopkins University as an instructor (1908/1909), then served as a research associate (1909–1911), and an associate professor (1911–1915), working on the improvement of reflection gratings for spectrographs, for which **Henry Rowland** had made the department famous. Anderson developed methods for making grating replicas and studied the effect of groove form on the distribution of light in various orders of diffracted light – thus preparing the way for the ruling of blazed gratings. He also oversaw the design and construction of a new ruling engine for gratings as large as 18 × 24 in. But the technical problems posed by the longer master screw and the heavier grating carriage turned out to be insurmountable, and smaller ruling engines proved better at making high-quality gratings.

A brief visit to Mount Wilson Observatory led to a permanent appointment there in 1916, from which Anderson officially retired in

1943, but he continued his involvement with instrumentation for the 200-in. telescope until its completion in 1948. Anderson participated in the effort by **Albert Michelson** to measure angular diameters of stars by interferometric methods and applied interferometry to determine the separation of close visual binary pairs. He made major contributions to the research of **Arthur King** and **Harold Babcock**, who were measuring the Zeeman and Stark effects on spectra of elements important in stellar atmospheres. During World War I, Anderson worked on micrometers and sonic submarine detection devices for the navy. Beginning in 1919, Anderson began experimenting with exploding wires in order to generate emission spectra of atoms and ions at temperatures up to 20,000 K, much higher than the 3,000 K possible in King's electric furnaces. The high temperatures lasted only a microsecond or less, and Anderson developed, with student **Sinclair Smith**, rotating mirror cameras with which the temporal changes in the spectra could be followed. He also developed a vacuum spectrograph for work at ultraviolet wavelengths.

Planning for the 200-in. telescope began with a grant of $6 million from the International Education Board (which **George Hale** had persuaded John D. Rockefeller to establish). Anderson was appointed Executive Officer, responsible for the optical components. He received a Gold Medal from the Franklin Institute in 1924 and was elected to the National Academy of Sciences in 1928 for his contributions to laboratory and astronomical optics.

Klaus Hentschel

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Ronald, Florence (1994). *The Perfect Machine: Building the Palomar Telescope.* New York: HarperCollins. (For Anderson's involvement with the 200-in. telescope.)

Anderson, Thomas David

Born **Edinburgh, Scotland, 6 February 1853**
Died **Edrom, (Borders), Scotland, 31 March 1932**

Although he had been trained for the ministry (M.A. University of Edinburgh), Thomas Anderson's accidental discovery of Nova Aurigae at 5th magnitude on 1 February 1892 (several months past its maximum brightness when it had not been observed by any other astronomer) prompted Anderson to devote the remainder of his life to the study of the night sky with the intention of discovering other new stars. Armed with only a modest telescope and the *Bonner Durchmusterung* [BD], but possessing unsurpassed diligence, Anderson is credited with the discovery of 50 variable stars but he discovered only one additional nova (Nova Persei, 1901). In the process, Anderson had updated his copy of the BD to include at least 70,000 additional stars that were fainter than the atlas' limiting magnitude. In recognition of his achievement, Anderson was the recipient of the Gunning Prize of the Royal Society of Edinburgh, the Gold Medal of the Société Astronomique de France, and the Jackson–Gwilt Medal of the Royal Astronomical Society. Anderson also received an honorary D.Sc. from the University of Edinburgh. Surprisingly, no obituary was ever published.

Thomas R. Williams

Selected Reference

MacPherson, Jr., Hector (1908). "Two Scottish Astronomers of Today." *Popular Astronomy* 16: 397–403.

Andoyer, Marie-Henri

Born **Paris, France, 1 October 1862**
Died **Paris, France, 12 June 1929**

Henri Andoyer contributed to three principal areas of scientific research: (1) observational and practical astronomy, (2) mathematical astronomy and celestial mechanics, and (3) textbooks and historical accounts. Andoyer's father was bureau chief at the Banque de France. The young Andoyer completed his secondary studies at the Lycée d'Harcourt. Later, he was admitted to the École Normale Supérieure and graduated at the top of his class in 1884, with a degree in mathematical sciences. That year, **Benjamin Baillaud**, director of the Toulouse Observatory, hired Andoyer as *astronome adjoint* and *chargé de conférences* at the Faculté des sciences at Toulouse.

Andoyer completed graduate coursework at the University of Paris and was awarded a doctorate in mathematical sciences in 1886. His dissertation (published the following year) was entitled, *Contribution à la théorie des orbites intermédiares* (Contribution to the theory of intermediate orbits). In 1887, he was named *aide-astronome* and *maître de conférences* at Toulouse. Two years later, Andoyer married Mademoiselle Périssé, from whom he had three children, two sons and one daughter. One of his sons was killed during World War I.

In 1892, Andoyer accepted the post of *maître de conférences* in celestial mechanics at the Faculté des sciences in Paris. Soon, he was named assistant professor, and in 1903, professor of astronomy. Upon the death of **Jules Poincaré** in 1912, Andoyer occupied the chair of general astronomy and celestial mechanics. Until 1905, he remained a member of the examination committee for mathematical sciences.

While at Toulouse Observatory, Andoyer was given charge of the new service of the *Carte du Ciel* in 1889. There, he became a pioneering figure in that vast international scientific enterprise. Before his departure for Paris, he devoted a large part of his time to the organization of celestial photography. Concurrently, Andoyer made observations of the satellites of Jupiter, meridian observations of the Moon, and observed minor planets, comets, and double stars. After the discovery of minor planet (246) Asporina in 1885, he calculated the orbital elements and projected an ephemeris for its opposition of 1885 and that of 1886.

Andoyer's studies in celestial mechanics were first carried out along the lines of **Hugo Gyldén**. One of the important classes of phenomena that Andoyer examined was that of near-commensurabilities or resonances. He studied the orbits of minor planets in which the mean motion was sensibly double that of Jupiter, *e. g.*, asteroid (108) Hecuba. Andoyer's work contributed to further explanation and acceptance of the gravitational explanation offered for the Kirkwood gaps in the asteroid belt, first enunciated by American astronomer **Daniel Kirkwood**. It was to this discipline that Andoyer was particularly devoted, as evidenced by his numerous memoirs on the subject. He proposed general methods of integration for solving problems in celestial mechanics and therefore extended the theorems of **Siméon Poisson**, relative to the invariability of the semimajor axes of planetary orbits.

Andoyer's most important research concerned the theory of the Moon's orbit. He determined the intermediate orbit of the Moon and, more specifically, the secular inequalities of the movements of its nodes and perigee. His comparison of various theories of the Moon allowed him to uncover differences between the results of **Charles Delaunay** and those of **Philippe le Doulcet de Pontécoulant**. Reporting the errors incumbent on the former, he concluded that "all the complementary terms calculated by Delauney beyond the seventh order are inexact; on the other hand, the earlier terms of the orders below the eighth, are in general exact." Andoyer examined the *n*-body problem, wherein he expanded upon the results of **Joseph Lagrange** concerning the equilibrium solutions for three bodies.

Andoyer's fundamental works are represented in the two-volume outline he prepared for his *Cours d'Astronomie de la Faculté des Sciences*: *I – Theoretical Astronomy* (1906), and *II – Stellar Astronomy* (1909), along with his two-part *Cours de Mécanique céleste* (1923 and 1926). Andoyer produced several textbooks on mathematical analysis and a three-volume work on trigonometric tables. He also published a scientific biography of **Pierre de Laplace**.

A member of the Paris Académie des sciences in 1919, Andoyer was also made in 1909, president of the Commission of Ephemerides of the Permanent International Council for the execution of the photographic *Carte du Ciel*. A member of the Bureau des longitudes in 1910, he was appointed editor (1911) of the *Connaissance des Temps*, the French nautical almanac. Andoyer was named an *Officier de la Légion d'honneur*.

Jérôme Lamy
Translated by: *Theresa Marché*

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J. J. (1930). "Marie Henri Andoyer." *Monthly Notices of the Royal Astronomical Society* 90: 384–386.

André, M. Charles

Born **Chauny, Aisne, France, 7 March 1842**
Died **Saint-Genis-Laval, Rhône, France, 6 June 1912**

Charles Wolf brought Charles André to the Paris Observatory, but André soon left to direct the Observatoire de Lyon. André investigated why the minor planet (433) Eros varies in brightness (rotation). He was also a veteran of the 1874 transit of Venus expeditions.

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Anon. (1912). "Prof. Charles André." *Nature* 89 : 429.

Angelus

➔ **Engel, Johannes**

Ångström, Anders Jonas

Born **Hässjö, Sweden, 13 August 1814**
Died **Uppsala, Sweden, 21 June 1874**

Anders Ångström was an astronomical observer, physicist, and a pioneer in spectroscopy. His father Johan was a clergyman in the Lutheran church of Sweden. Ångström and his two brothers, Johan and Carl, all received higher education. Carl became a professor of mining technology; Johan became a physician and well-known botanist. Ångström studied at Uppsala University, and in 1839 he became a *docent* in physics there. As the professor in physics was a fairly young man, and as there were no other academic positions in physics other than the professorship, Ångström switched to astronomy, where there was a position as astronomical observer at the university.

During the 1840s and 1850s Ångström worked as astronomical observer and acting professor of both astronomy and physics at Uppsala University. He did research in various fields during these years, for example in geomagnetism and the heat conduction of metals.

By the time he was appointed regular professor of physics, in 1858, Ångström had already published one of his two most famous contributions to the new scientific field of spectroscopy. The paper *Optical Researches* was published in Swedish in 1853 and in English and German 2 years later. In it Ångström has presented, in an unsystematic fashion, a number of experimental results concerning the absorption of light from electrical sparks in gases. He also made theoretical interpretations indicating, among other things, that gases absorb light of the same wavelengths that they emit when heated, and suggesting, somewhat obliquely, that the Fraunhofer lines could be explained in this way.

During the priority disputes that followed **Gustav Kirchhoff**'s publication of the law of absorption and the explanation of the Fraunhofer lines around 1860, Ångström and his collaborator at Uppsala University, Robert Thalén, vigorously defended the Swede's priority. Their claims were to some extent recognized also in Britain when the Royal Society elected Ångström foreign member in 1870 and awarded him the Rumford Medal 2 years later. These honors were also given in recognition of Ångström's other important spectroscopic work, an atlas of the solar spectrum published in 1868. Much of the painstaking work that went into the atlas of the Fraunhofer lines (identified by wavelengths, which led to the designation *Ångström* being used for the unit of length 10^{-10} m) had been carried out by Thalén, though Ångström appeared as sole author of the work. During the 1860s and 1870s Ångström and Thalén carried out a great number of spectroscopic measurements, not only on the Fraunhofer lines but also on the wavelengths of emission spectra of many substances.

During these decades and into the early 1880s, Ångström and Thalén dominated European spectroscopy. A measure of their influence is the publication of lists of spectroscopic data for the elements carried out by the British Association for the Advancement of Science [BAAS] in the mid-1880s. Of 67 elements, measurements by Ångström and Thalén (mostly by the latter) were given for 60; no other spectroscopists came close to that figure. Ångström's atlas was used as standard reference by the BAAS, though it was soon to be superseded by the photographic atlas of **Henry Rowland**.

Ångström became a member of the Royal Swedish Academy of Sciences in 1850, of the Prussian Academy of Sciences in 1867, of the Royal Society in 1870, and of the French Academy of Sciences in 1873. He was elected a member of several other Swedish and foreign scientific societies as well.

In 1845 Ångström married Augusta Bedoire, and they had four children, two of whom survived to adulthood. Their son Knut became a professor of physics at Uppsala University, succeeding his father's successor Robert Thalén in 1896. Their daughter Anna married Carl Gustaf Lundquist, a student of her father's, who in 1875 succeeded Thalén as professor of theoretical physics. There were additional family ties between the Ångströms and other scientific families at Uppsala. Hence, Anders Ångström was a founder not only of the science of spectroscopy but also of a scientific dynasty.

Sven Widmalm

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Anthelme, Voituret

Born **probably France, 1618**
Died **probably France, 1683**

Voituret Anthelme was a French astronomer specializing in comets. Although he was a monk in a Catholic monastery, he spent much of his time studying stellar motions and searching for comets. Anthelme discovered several comets and investigated the cause of the brightness change of the variable star Mira. Using his own observations of comet C/1680 V1, he published *Explication de la comète* in 1681. Anthelme's idea on cometary orbits was that one of the foci of an orbit is located far away from the Earth, so that their orbital eccentricity is extremely large. He argued that comets are made of transparent materials, contrary to the vortex hypothesis proposed by **René Descartes**.

K. Sakurai

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Antoniadi, Eugène Michael

Born **Istanbul, (Turkey), 1 March 1870**
Died **Paris, France, 10 February 1944**

Eugène Antoniadi was one of the leading visual observers of the planets in the late 19th and early 20th centuries. Born of Greek parents, Antoniadi became interested in astronomy during his boyhood. His talent for beautiful draftsmanship became evident at an early age; it appears he received at least some formal training in architecture. When he was only 17, Antoniadi began making drawings of sunspots and the planets with a 3-in. refractor at Constantinople and on the island of Prinkipio in the Sea of Marmara. He began submitting his work to the Société Astronomique de France, which had been founded in 1887 by **Camille Flammarion**. At this time, conditions in the Ottoman Empire were worsening under Sultan Abdülhamid II – the Red Sultan – and Antoniadi was eager to escape his disordered homeland. He accepted an invitation to become assistant observer at Flammarion's private observatory, located at his chateau at Juvisy-sur-Orge, between Paris and Fontainebleau.

Antoniadi began work under Flammarion whom he addressed as "my dear Master" in 1893. Although working at the observatory, Antoniadi lived in Paris. He frequently contributed articles to both Flammarion's journal *L'Astronomie* and the *Journal of the British Astronomical Association*. Antoniadi already was equally fluent in English and French, though he had little appreciation for American English; he once commented, "Reading the *New York Herald* after Gibbon gives me nausea. The Americans are seriously damaging the language."

In 1896 Antoniadi succeeded Bernard E. Cammell as director of the British Astronomical Association Mars Section, and remained in this position for more than 20 years. Eventually, his relationship with his "dear Master" became more and more strained. In part it seems Antoniadi resented Flammarion's tendency to appropriate credit for his own work. (His contract called on him to keep a notebook for Flammarion, and four volumes of his splendid drawings are still preserved at Juvisy). Then too, Antoniadi's own desire to achieve more independence may have played a role in this estrangement. In particular, Antoniadi was having private doubts about the reality of the so called canals of Mars, regular linear markings with which he had covered his earlier maps with Flammarion's blessing. Antoniadi's health was beginning to suffer, and in 1902 he resigned his position at Juvisy, and briefly pondered a move to England.

However, at about this same time Antoniadi acquired financial security – through marriage to Katherine Sevastapulo, whose parents were also Greek and seem to have been very well off – and he did not take a salaried position again for the rest of his life. He and Katherine moved to rue Jouffroy, located in a tony district of Paris, and for a number of years the pursuit of architectural matters seems to have overtaken his interest in astronomy. He obtained permission from the Red Sultan himself to draw and photograph the interior of Saint Sophia in Constantinople. This effort led to the publication, in 1907, of a three-volume work (in Greek) on the architectural masterpiece.

Antoniadi's return to astronomy came with the favorable opposition of Mars in 1909. In August, he recorded dust clouds on the planet from rue Jouffroy, using an 8½-in. reflector. He described Mars as covered with a "pale lemony haze." Soon afterward, Antoniadi received an invitation from **Henri Deslandres**, director of the Meudon Observatory, to observe the planet with the Grand Lunette, the 33-in. (83-cm) Henry Brothers refractor, and – as Richard McKim has noted – "his drawings of the 1909 apparition were unsurpassed both artistically and areographically." It is clear that his drawings, which can now be compared with charged-couple-device images of the planet, were remarkably accurate in their depiction of the main features of the Martian surface. With the great telescope, Antoniadi saw Mars "more detailed than ever;" the planet's appearance resembled that of the Earth as he had seen it in 1900 from a balloon at a height of 12,000 ft. He figured "a vast and incredible amount of detail," and presented a devastating assault on the reality of the canal network. The latter, he was convinced, was an illusion presented in small apertures or under indifferent conditions of "seeing." He announced this privately in correspondence to the leading canal advocate of the day, **Percival Lowell**, and published his observations and conclusions in a series of interim reports in 1909 and 1910 and in a memoir on the opposition that appeared in 1916.

His work during the 1909 opposition established Antoniadi as the leading authority on Mars – a position that he consolidated in his work at later oppositions (except during the war years) – and by publication of his great book *La Planète Mars* (1930). He was also a prolific observer of other planets, notably Mercury, the subject of a careful study with the Meudon refractor between 1924 and 1929. Though the work was carried out with great care, it is obvious that Antoniadi was unconsciously influenced by the earlier study by the Italian astronomer **Giovanni Schiaparelli**. He reached the same erroneous conclusions about the planet's rotation (which he regarded as synchronous with the period of revolution, 88 days) and the presence of frequent and obscuring dust clouds. His book on Mercury, published in 1934, is a record of mirages.

Antoniadi regarded himself as a "volunteer observer" at Meudon. He possessed a "naturally curt manner," and preferred to work in isolation, though he maintained an extensive correspondence with astronomers overseas. He was a perfectionist, a man of high standards; he rarely found others who could live up to those he imposed on himself. He was known – but just – by some of the leading planetary observers of the next generation, for example Henri Camichel who met him, but never assumed the role of a mentor to them.

The frequency of Antoniadi's observational work with the great refractor declined during the 1930s. He still railed against the Martian canalists, and devoted much time to investigating the astronomical ideas of the ancient Egyptians, about which he published a book the same year his memoir on Mercury appeared. On the other hand, he had no use for modern ideas of astrophysics or relativity.

With the occupation of Paris on 14 June 1940, Antoniadi's overseas contacts were cut off, and soon afterward he gave up his work at Meudon. The bitter war years undoubtedly depressed him; during these dark years his health began to fail as well. Sometime before he died – 6 months before the liberation of Paris – he destroyed all his unpublished records.

William Sheehan

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Apian, Peter

Born **Leisnig, (Sachsen, Germany), *circa* 1501**
Died **Ingolstadt, (Bavaria, Germany), 1552**

Very little is known about uranographer Peter Apian' s early life. Some confusion exists among the family records. The earliest unequivocal reference to his career is among the matriculation records of the University of Leipzig in 1516. It was at Leipzig that he Latinized his family surname from Bienewitz to Apianus (from the Latin word for "bee"), before subsequently moving to the University of Vienna. At Vienna, Apian studied with Georg Tannstetter, a renowned teacher of astronomy and former personal physician to Emperor Maximilian I, and he also brought out his earliest known publication, a map of the world that was printed in 1520.

Edmund Halley's prediction that the comet he observed in 1682 would return again 76 years later is credited as the earliest recognition of cometary periodic orbits. A prior appearance of comet 1P/Halley in 1531, however, was also responsible for prompting a less well-remembered

discovery concerning the nature of comets. In the earlier instance, Apian observed this comet over many nights and noted for the first time that regardless of its position, a comet' s tail always points away from the direction of the Sun. He described his observations in a printed astrological prognostication for the year 1532, in which he also included a woodcut illustration showing the comet' s motion relative to the Sun. Observations of three more comets in later years allowed Apian to confirm this discovery, although like virtually all of his contemporaries, he continued to believe that comets were a product of the Earth' s upper atmosphere rather than independent celestial bodies.

Apian' s 1520 world map was a forerunner to a long succession of publications that he produced throughout his life for both scholarly and general audiences. Most of these works appeared either from his brother' s printshop in Landshut or from his own printshop in Ingolstadt, where he was appointed a professor of mathematics at the university in 1527 and subsequently taught for nearly 25 years. As a cartographer, Apian published further maps of the world and different European regions, as well as maps of the celestial constellations, and he wrote an introductory text on geography that became immensely popular. The latter work, simply entitled the *Cosmographicus Liber* (Cosmographical book), went through dozens of printed editions in Latin, Dutch, French, and Spanish, especially in a form that was edited by the Dutch mathematician **Gemma Frisius**, and remained a staple textbook across Europe until the end of the 16th century.

Apian produced other well-illustrated books in both Latin and German describing measurement techniques for a wide range of mathematical instruments, and he also wrote an instructional manual on commercial arithmetic. In addition, a 500-page volume reproducing ancient Roman inscriptions from across Europe, which he edited along with his fellow Ingolstadt professor Bartholomew Amantius, gives ample evidence of both the breadth of Apian' s scholarly interests and the advanced technical capabilities of his printshop.

In the realm of astronomy, Apian wrote books on several instruments of his own design that could be used for timekeeping or for making celestial observations, and he published new editions of **John of Holywood**'s *Sphere*, **Georg Peurbach**'s *New Planetary Theories*, and **Jabir ibn Aflah**'s *Nine Books on Astronomy*. Like his astronomical colleagues at many other universities, Apian issued regular calendars and short astrological forecasts such as the ones that included his observations on comets.

Apian's most famous publication, however, was the *Astronomicum Caesareum* (Imperial astronomy), brought out in 1540 and dedicated to Emperor Charles V and his brother Ferdinand. A spectacular achievement of Renaissance printing, this volume allowed its user to reproduce the motions of all the heavenly bodies through combinations of elaborately decorated rotating paper disks up to six layers deep and arranged on nonconcentric axes. For this work, Apian was rewarded by the emperor with 3,000 gold coins and elevated to membership among the hereditary nobility, as well as bestowed other honors and privileges. After his death, his son Philipp, one of 14 children with his wife Katharina Mosner, succeeded to Peter' s mathematical chair at the University of Ingolstadt.

Karl Galle

Alternate name

Petrus Apianus

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Apollonius of Perga

Flourished **Alexandria, (Egypt), *circa* 247-205 BCE**

Apollonius laid two foundations, one in astronomy and the other in mathematics.

Ancient sources have Apollonius flourishing in the reign of Ptolemy Euergetes (Ptolemy III: 247–222 BCE) and Ptolemy Philopator (Ptolemy IV: 222–205 BCE). He was born in Perga (near the southern coast of what is now Turkey), and moved to Alexandria, where he spent his working life. The move to Alexandria may have been spurred by Euergetes' naval forces conquering the coastal regions all the way to the Hellespont early in his reign, which made Alexandria the capital of the entire eastern Greek world.

In astronomy, **Ptolemy** used Apollonius as his authority on epicycles and eccentrics to account for the apparent motions of the planets. The propositions cited by Ptolemy as proven by Apollonius show mathematically at what points the planet appears stationary, switching from apparent forward to apparent retrograde, and vice versa.

In mathematics, Apollonius's *Conics* give us the concept and nomenclature for ellipse, parabola, and hyperbola. These curves originate with the mental exercise of pushing a plane through a cone and contemplating the shape of the intersection. Apollonius found a new generalized way to describe the properties of all three conic sections, and went on to discuss a number of problems connected with them. The *Conics* were originally in eight books; books I–IV survive in the original Greek, and books V–VII survive in Arabic. They were studied by Arab astronomers and by **Johannes Kepler**, **René Descartes**, **Edmund Halley**, and **Isaac Newton**.

Thomas Nelson Winter

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Appleton, Edward Victor

Born **Bradford, England, 6 September 1892**
Died **Edinburgh, Scotland, 21 April 1965**

British radio engineer and space physicist Edward Appleton received the 1947 Nobel Prize in Physics for his discovery of the layer in the Earth's ionosphere that reflects short wavelength radio. He was the eldest of three children of warehouseman and church-organist Peter Appleton and his wife Mary; he married Jessie Longson in 1916 (and had two daughters) and, after her death, Helen Lennie in 1965. Appleton developed an interest in physics at the Hanson School in Bradford, and went to Cambridge University to read natural sciences at Saint Johns College in 1911, receiving a first-class degree in 1914. His studies included geology and mineralogy, especially the optical properties of crystals, as well as physics. After graduation, Appleton became the first research student of William Bragg, intending to work on X-ray crystallography. Both, however, volunteered for service at the outbreak of World War I.

Appleton was assigned to the Royal Engineers, being employed primarily as an instructor with a signals unit, but also investigating the possibility of eavesdropping on radio communications – his first exposure to radio technology, of whose importance he was quickly persuaded. He returned to Cambridge and began work as a research (graduate) student with J. J. Thomson, receiving in due course an M.Sc. (1919) and a D.Sc. (1921), both external degrees from the University of London for work on radio wave generation, propagation, and detection.

In 1924, Appleton was appointed to the Wheatstone professorship of physics at King's College, London, taking with him a new student, Miles A. F. Barnett. The probability of a radio-reflecting layer somewhere in the Earth's atmosphere was already clear from the experiments of Guillermo Marconi (transmission of radio waves across the Atlantic in 1901) and theoretical considerations by Arthur E. Kennelly and Oliver Heaviside (hence the Kennelly–Heaviside layer). But Appleton and Barnett devised a method to trace out the location and properties of the layer, thereby definitely establishing its existence. They persuaded the British Broadcasting Company [BBC] to sweep the frequency of its transmitter at Bournemouth back and forth while they sat at Oxford measuring the intensity of the received signal. The two cities are about 75 miles (120 km) apart, the perfect distance for what Appleton and Barnett were trying to do, which was to see the interference between radio signals that traveled along the ground and those that had been bounced off the reflecting, partly ionized layer. Wavelengths of a meter or two were nicely reflected at about 100 km, and the height varied between day and night and with the seasons, showing that radiation from the Sun was responsible for what radar pioneer Robert Watson-Watt later named the ionosphere.

In practice, the first discovery (now called the E layer), and the one higher in the atmosphere at 200–300 km (which reflected shorter wavelengths and is now called the F layer), were generally called the Appleton layers. A lower-lying D layer at about 70 km is closely associated with the name of **Sydney Chapman**. Very similar investigations were also under way by 1924 in the United States, with **Edward Hulburt** and E. Hoyt Taylor working at the Naval Research Laboratory, and Gregory Breit and Merle Tuve at the Carnegie Institution. Nevertheless, Appleton was considered to have got the answer first, and most clearly, and received the Nobel Prize (as well as many other honors) for it. He took up a professorship at Cambridge University in 1938, but less than 3 years later (as war returned), he was asked to take over the secretaryship of the Department of Scientific and Industrial Research [DSIR].

Appleton headed DSIR until after the end of World War II and provided leadership to the national efforts in ionospheric research (for communications and intelligence purposes) as well as radar and atomic weapons. Toward the end of the war, he foresaw a need for ongoing, peacetime, government-sponsored research and played a leading role in the establishment of the Harwell Research Laboratory near Oxford. Another laboratory there, also engaged in a variety of kinds of physics and related research (much of it with defense implications), is now called the Rutherford–Appleton laboratory.

One of the key junior wartime workers in radar was **Bernard Lovell**, who after 1945 developed plans for a major research effort in radio astronomy at Jodrell Bank (near the University of Manchester). Appleton helped to ensure that government funding supported this program.

From 1934 to 1952, Appleton was president of URSI (the French acronym of the International Union of Radio Science) and lent his prestige to its activities, including the sharing out of available radio frequencies among defense, civilian communication, and astronomical research. He also started a research journal, which, under the title of *Journal of Atmospheric and Solar-Terrestrial Physics*, remains important in the field he helped to found. Appleton accepted the post of vice chancellor and principal of the University of Edinburgh in 1949. He maintained a section for ionospheric research there, but was himself increasingly involved in administration and plans for substantial expansion of the university. Although somewhat beyond standard retirement age, Appleton still held the post at the time of his death.

Peter S. Excell

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Aquinas, Thomas

Born **Rossasecca, (Lazio, Italy), *circa* 1223**
Died **Fossanova, (Lazio, Italy), 5–7 March 1274**

Thomas Aquinas' importance to the history of astronomy lies in his reconciliation of Aristotelian cosmology and 12th-century astrology with Christian theology.

Saint Thomas Aquinas was the foremost Catholic theologian of the medieval world. Born into an aristocratic south Italian family, he became a Dominican Friar at the age of 16. In 1245 he arrived in Paris, where he became a student of **Albert the Great**, the most prominent exponent of Aristotelian philosophy. Aquinas took his bachelor's degree in 1248, returning to Paris in 1253 to prepare for his master's degree, which he received in 1257. He was sent to Italy to teach in various Dominican houses in 1259, returned to Paris in 1269, and was sent to Naples in 1272 to set up a Dominican school. His reputation in the modern world was affirmed in 1879 when Pope Leo XIII named him "the chief and master among all the scholastic doctors" in his encyclical *Aeterni patris*.

Aristotle's work had become familiar to Western scholars in the 12th century partly through original translations, notably the *Meteorologica* (translated by Henry Aristippus between 1150 and 1160) and partly through the work of Arabic scholars such as Avicenna (**Ibn Sina**) and Averroes (**Ibn Rushd**). The overall effect of this material was quite revolutionary. It introduced into Catholic learning the work of a philosopher who had accepted **Plato**'s doctrine of a single God, and hence whose work seemed compatible with Christianity, but argued for the eternity of the Universe, thus denying both the reality of the Genesis creation myth and the possibility of the Last Judgment and inauguration of the Kingdom of God. The introduction of Aristotelian material was accompanied by the translation of major astrological texts, particularly Claudius **Ptolemy**'s *Tetrabiblos* (1138), the pseudo-Ptolemaic *Centiloquium* (1136), and the *Maius Introductorium* (1140), the major introduction to astrology composed by the Persian astrologer **Abu Ma'shar**. Combined with Aristotle's statement that "the celestial element, … [the] source of all motion, must be regarded as first cause" (*Meteorologica* I.ii), such work established astrology as a central feature of Western science and an integral part of medieval astronomy. If, for example, an understanding of the wider celestial environment was essential to the analysis of events on Earth, then astronomy now possessed directly practical applications in the treatment of disease, the prophecy of peace and war, the prediction of individual fortunes, and the selection of auspicious moments to inaugurate important enterprises.

The extent of Aquinas' writing is immense, and his highest achievement was the *Summa Theologica*, a complete systematization of Christian theology. His writings on the stars are contained in the *Summa contra Gentiles*, a textbook for missionaries, which summarizes the arguments to be put in response to various nonscriptural claims. All 13th-century Catholic theologians were obliged to take a position *vis-à-vis* Aristotelian teaching, its implications for astronomy, and the safe philosophical ground it provided for astrology. Many were hostile. Aquinas, following Albertus Magnus' example, was openly sympathetic to both Aristotle and the associated astrological texts, and his contribution to the history of astronomy lies in the third way he established between astral determinism and the requirement, central to Christianity, that the individual must be able to make a free choice between good and evil and thus achieve salvation. Saint **Augustine**'s solution, which was still prevalent in the 13th century, was that the stars had no influence at all and that all power lay with God. Aquinas' alternative solution, set out in *Summa contra Gentiles* (Chapters 83–88), allowed the stars, as secondary causes in an Aristotelian sense, to rule the physical world, while retaining the Augustinian doctrine that the human will, and hence the chance of salvation, was responsible to God alone. Thus any form of astrology that dealt with the consequences of natural disorder or physical passion was permissible. Medical astrology was acceptable, as was the prediction of war and peace. The election of auspicious astronomical moments to inaugurate new enterprises was deemed unacceptable because it impinged on God's providential right to dictate the outcome of events, as was the use of interrogations, the casting of horoscopes to answer precise questions about the future. Genetheliacal astrology, which dealt with individual lives, was acceptable in as much as it dealt with physical existence, but not if it denied moral choice.

Aquinas' work was condemned at Paris in 1277, but in 1278 the Dominican General Chapter officially imposed his teachings upon the order. His moral cosmology remained an influential component within Catholic thinking on astronomy until the 17th century and provided a rationale for astrology that was unavailable within more conservative wings of the Church, which remained loyal to Augustine.

Nicholas Campion

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Arago, Dominique-François-Jean

Born **Estagel, (Pyrénées-Orientales), France, 26 February 1786**
Died **Paris, France, 2 October 1853**

François Arago directed the Paris Observatory, was a patron of **Urbain Le Verrier**, and made significant contributions to the physics of light and electromagnetism. Arago was the fifth son in a family of 11 children raised by François Bonaventure Arago and Marie Roig. Born in the small town of Estagel in Roussillon close to the Spanish border, he was part of a middle-class family of farm origins. His father, who, in 1774, passed his school-leaving examination with the right to enter the University of Perpignan, became mayor of Estagel in 1789 and led a lively public career until his death in 1815.

It was a mark of his growth as a youth that, in 1795, François Arago moved with his family to Perpignan to commence his secondary studies, which he abandoned in 1800 to prepare himself for entrance into the prestigious École Polytechnique de Paris.

In Toulouse, in 1803, he passed the entrance examination for the École Polytechnique and moved to Paris to take up his studies. Two years later, his friend **Denis Poisson**, with the aid of the all-powerful **Pierre de Laplace**, proposed him officially for the post of secretary of the Paris Observatory, a position that had been left vacant by the negligent Augustin Méchain, son of the astronomer of the same name, and that Arago filled temporarily from the end of 1804. On 22 February 1805, he was effectively named to a post at the Bureau of Longitudes, on which the observatory depended.

The young Arago's astronomical career began at the Paris Observatory. After meeting with **Jean Biot**, an already recognized scientist, they worked out a plan to complete the geodesic operations that **Pierre Méchain** had left uncompleted in Spain. With the support of Laplace, Biot and Arago were designated to complete the work of extending the meridian of Paris as far as the Balearic Islands in the Mediterranean Sea, a task they performed between 1806 and 1808.

On his return to Paris in July 1809, after many vicissitudes, Arago took possession of the post of *astronome adjoint* at the Bureau of Longitudes, a position to which he had been appointed, *in absentia*, in 1807. Two months later, on 11 September, again with the support of Biot and Laplace, he was elected as an astronomer to the Paris Academy of Sciences, in his 23rd year, with 47 of the 52 votes cast. With the confirmation of this appointment by Emperor Napoléon on 23 October 1809, Arago became a public figure. Also in 1809, he succeeded Gaspard Monge in the chair of analytic geometry at the École Polytechnique.

From his post in the academy and as a member of the Bureau of Longitudes, Arago assumed the effective control of the Paris Observatory. Formal control of the observatory fell to the bureau in a collegial way, although always one of its members took responsibility for the establishment. From 1809, this happy responsibility fell upon Arago, who then moved into a building of the observatory in 1811, after his wedding. On 9 April 1834, in recognition of the actual situation, Arago was named "director of observations," a post he would hold until his death. He had two sons, Emmanuel and Alfred, from his marriage.

At the Paris Observatory, Arago began to consolidate his scientific career, which primarily developed between 1809 and 1830. A physicist more than a positional astronomer, Arago mainly occupied himself with the subject of light, its properties, and the instruments for its study. His first discoveries came in 1811 in the area of polarization of light, just before the discoveries of Etienne Malus. In this year he invented an instrument that measured the angle of polarization, and with polarized light he carried out various experiments that convinced him of the superiority of the wave theory over the corpuscular theory of light.

As a member of Parisian cultivated society at the beginning of the century, Arago forged good friendships with important people. Having close relations with J. -L. Gay-Lussac and **Alexander von Humboldt**, he was occasionally invited to the Société d'Arcueil, private meetings encouraged by Claude Berthollet and Laplace, and began surrounding himself with other promising young men. Among his closest friends at the time were Malus (died: 1812), Claude Mathieu, Augustin Fresnel, and André-Marie Ampère, but he was estranged from his first friend, Biot.

In the midst of political changes in post-Napoleonic France, and from his post at the observatory, Arago specialized in the study of light and the phenomena of electromagnetism. He discovered chromatic and circular polarization of light and investigated refraction in solids and liquids. Defender of the wave theory in opposition to Laplace and Biot, but supported by Fresnel, he was little by little able to overcome the resistance to the theory within the academy. With his support, Joseph Fourier was elected perpetual secretary, and Arago succeeded him in June 1830.

In fact, after the fall of Charles X, in July 1830 Arago was elected a deputy. From the Chamber of Deputies and the Academy of Sciences, he promoted important initiatives in science policy and education, while at the observatory he encouraged research plans. Le Verrier, for example, owed to him the suggestion to carry out investigations that led to the discovery of Neptune.

From his high posts, Arago looked out for the careers of the young physicists and astronomers around him. In addition to the polarization of light, he studied the velocity of light, terrestrial, and celestial bodies, the phenomena of refraction, and the recently invented photography. Arago was now at the beginning of a stage in his career as a successful science popularizer and more and more turned his attention to political life.

In spite of his much lesser discoveries in fields as far from astronomy as geodesy, optics, electromagnetism, or meteorology, Arago's primary activity was as a cheerleader for science rather than as a pure scientist. A convinced and outspoken republican, he promoted the abolition of slavery in French territories and, after the Revolution of 1848, was named minister of marine and war, a post he held for 4 months. Arago was skillful at emphasizing new ideas, important among them being the discoveries in optics, astronomy, and technology. Almost blind during his last years and more preoccupied with politics than with pure science, he died, still in his position of director, to which the rival of his last years, Le Verrier, would succeed.

Antonio E. Ten
Translated by: Richard A. Jarrell

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Aratus

Born **Soli (near Mersin, Turkey), late fourth century BCE**
Died **Pella, (Macedonia, Greece), before 240 BCE**

Aratus is the author of the *Phaenomena*, a description in poetry of the constellations and the apparent motions of the sky, which was widely read throughout Antiquity and the Middle Ages.

After studying with Stoic (and Peripatetic?) philosophers in Athens, Aratus was invited, in 276 BCE, to the court of Antigonus Gonatas in Pella, where he seems to have spent most of his active career as a scholar and poet. Ancient sources, besides offering many less trustworthy biographical details, ascribe to Aratus occasional poetry (*e. g.*, celebrating Antigonus' marriage), a collection of "light verse" (*Kata lepton*), epigrams, hymns, epistolary character sketches, and an edition of **Homer**.

But Aratus was best known for his didactic poems on anatomical, pharmacological, and especially astronomical subjects. The *Kanôn* (measuring rod) probably held a mathematical description of the planetary orbits. The first part of the *Phaenomena*, Aratus' only surviving major work, contains a catalog of the makeup and relative position of the constellations and is laced with stories about their mythological origin. The description passes from the poles and the northern constellations to the southern constellations, the principal circles of the celestial sphere, the risings and settings of the 12 signs, and finishes with the movements of the Moon and the Sun (lunar month and seasons) and their influence on human affairs. The second part of the poem, which bears the separate title *Diosemeiai* ("Weather signs") contains practical advice on forecasting the weather by observing the skies and other natural phenomena.

The poem generally emulates the *Works and Days* of **Hesiod**, and supplements that work by providing the description of the constellations that Hesiod presupposes, and by offering instructions to seafarers (*i. e.*, traders) rather than farmers. This is one of many indications that, just as *Works and Days* is representative of the society of archaic Greece, Aratus wanted his poem to reflect the new, cosmopolitan worldview propagated at the Hellenistic courts. The Stoic Zeus whom Aratus invokes in his introduction stands for the "first cause" guaranteeing cosmic order, which on the human level is represented by the ruler. Aratus' work is therefore, just like that of Hesiod, concerned with the principle of *dikê* (good order).

The *Phaenomena*, already regarded as Aratus' masterpiece by contemporaries, remained widely read throughout Antiquity. It evoked many commentaries (*e. g.*, by **Hipparchus** and **Theon of Alexandria**), translations, and reworkings (*e. g.*, by Varro Atacinus, **Cicero**, **Virgil**, Germanicus, **Manilius**, and Avienus). Although this popularity was mostly driven by admiration for Aratus' successful transformation of "dry" scientific material into elegant, sophisticated verse, it also had an impact on the history of astronomy by divulging (and, finally, preserving) the ideas of **Eudoxus** (Aratus' main source for the section on the constellations) and peripatetic meteorological doctrine (taken from a work by **Aristotle** or **Theophrastus**). Aratus' sources were not widely read outside "professional" circles, the general educated public took its astronomical and meteorological instruction largely from the *Phaenomena* and commentaries on it. In the Middle Ages, the work continued to circulate in Greek (as part of the Byzantine school curriculum), Latin (the socalled *Aratus Latinus*), and Arabic, but it gradually lost ground to **Ptolemy**'s *Almagest*.

Martiin P. Cuypers

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Archelaus of Athens

Flourished **(Greece), 5th century BCE**

A disciple of **Anaxagoras**, Archelaus held a cosmological view similar to that of his mentor. However, Archelaus saw no need for a creative force (*nous*).

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Archenhold, Friedrich Simon

Born **Lichtenau, (Hessen, Germany), 2 October 1861**
Died **Berlin, Germany, 14 October 1939**

Astronomy popularizer Friedrich Archenhold completed his secondary education at the Realgymnasium in Lippstadt. In 1882, he began to study the natural sciences at the Friedrich Wilhelm University (now Humboldt University) in Berlin. There, Archenhold came under the influence of Wilhelm Förster, director of the Berlin University Observatory, who was committed to diffusing scientific knowledge among the public. In 1888, Förster and Archenhold cofounded the Urania Astronomical Society as an outreach function of the observatory.

From 1890 to 1895, Archenhold served as astronomer and manager of the Grunewald Observatory, a small station located outside the city of Berlin. In 1893, he began a campaign to construct a large telescope in Germany. Three years later, this was accomplished with construction of the longest refracting telescope in the world, a 26.8-in. (68-cm) objective with a focal length of 69 ft. (21 m), financed by private donations. The new Treptow Observatory had an original, timber-supported framework (as demonstrated at the Treptow Industrial Exhibition of 1896). That wooden structure was replaced, however, when the present main building was constructed in 1908–1909. Archenhold served as director of the Treptow Observatory from 1896 to 1931.

Archenhold developed an active program of events and publications, while the observatory itself was supported by a voluntary organization. In 1900, he founded the popular astronomical magazine *Das Weltall* (The Universe), which was published until 1944. He also traveled widely to places such as Sweden, Great Britain, Spain, and the United States. In 1907, Archenhold was awarded an honorary doctorate by the Western University of Pennsylvania. Always interested in the educational potential of new media, he established a "cinematographic study society" to aid the production of scientific films (1913). Archenhold was also a leading member of the Panterra Organization that promoted international research projects of a peaceful nature. He subscribed to the Jewish faith.

Archenhold resigned his post in 1931 at the age of 70. After the Nazis came to power, his family members were gradually expelled from the observatory. His sons Horst and Günter (who also became an astronomer) immigrated to England, but Archenhold's wife Alice and daughter Hilde lost their lives in the Theresienstadt concentration camp.

Archenhold was an original and, on occasion, a somewhat outlandish personality and the subject of countless anecdotes. From his broad outlook, he successfully advocated the placement of large astronomical telescopes on mountaintops, the construction of a projection planetarium in Berlin, and the production of inexpensive telescopes for school districts. In 1946, the Treptow Observatory was renamed the Archenhold Observatory after its founder.

Dieter B. Herrmann
Translated by: Peter Nockolds

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Archimedes

Born **Syracuse, (Sicily, Italy), 287 BCE**
Died **Syracuse, (Sicily, Italy), 212 BCE**

Archimedes is widely regarded as the greatest mathematician of Antiquity and one of the greatest mathematicians of all time. He lived in Syracuse on the island of Sicily, and was a *protégé* of its kings Hieron and Gelon. Archimedes was killed by a soldier during the Second Punic War between Rome and Carthage. Episodes in the life of Archimedes have become legendary, the information coming in large part from **Plutarch's** account in his description of the conquest of Syracuse by Rome in his *Life of Marcellus*.

The contributions of Archimedes to astronomy are less well known. There was a lost work on optics, *On Catoptrica*, some of which is transmitted in a commentary by **Theon of Alexandria** on **Ptolemy's** *Almagest*. **Cicero**, who was treasurer of Sicily in 75 BCE, wrote that spheres built by Archimedes were brought to Rome by Marcellus and that one of these was a planetarium, a mechanical model showing the motions of the Sun, the Moon, and the planets. It is believed that Archimedes wrote a paper on the construction of his planetarium, *On Sphere Making*, as is mentioned by **Pappus**. Since lost works of Archimedes were rediscovered as late as 1900, it is not inconceivable that these works may eventually be found.

The surviving astronomical work of Archimedes is contained in his *The Sand Reckoner*, and the rest of this article is concerned with this work. Apart from its inherent contributions, *The Sand Reckoner* might be the best introduction to classical science.

Archimedes set for himself not just the task of calculating a number greater than the number of grains of sand not just on a beach, or on all of the surface of the Earth, or even the Earth filled with sand, but the task of calculating a number that would be greater than the number of sand grains that could fill up the whole Universe. To do this, he required, among other things, the circumference of the Earth in stades, and the distance between the center of the Earth and the center of the Sun in Earth radii. He saw the Universe as a sphere with the Earth at its center; the Sun revolved around the Earth in a circle. The ratio of the diameter of the Universe to the diameter of the Sun's orbit around the Earth is less than the ratio of the diameter of the Sun's orbit around the Earth to the diameter of the Earth.

Archimedes used known estimates on the circumference of the Earth. By this time, **Eratosthenes** had given his celebrated estimate of the Earth's circumference, coming up with a value very close to the correct 40,000 km. Archimedes' upper bound of 3 million stades is therefore consistent with his strategy of giving an estimate at least 10 times larger than the currently accepted figure.

Archimedes' estimate of the distance between the Earth and the Sun is more interesting; this appears to be one of the earliest attempts to determine this distance. His method was to use contemporary estimates for the size of the Moon relative to the Earth (relatively easy) and the size of the Sun relative to the Moon (very difficult). Since the Sun and Moon have the same angular diameter for a terrestrial observer, as seen during solar eclipses, it follows that the distances of the Sun and Moon from the Earth are proportional to their size. The distance to the Sun is then computed once the angular size of the Sun, as seen on the Earth, has been estimated, a measurement which Archimedes himself carried out experimentally.

The measurement was done by observing the Sun at sunrise, using a horizontal ruler on a vertical stand, and a cylinder placed on the ruler. The ruler is directed toward the Sun, and the eye is placed at the end of the ruler opposite the Sun. The cylinder blocks the Sun from the eye, and is moved away from the eye until a small piece of the Sun can be seen. The resulting angle between the sides of the cylinder and the eye, imagined to be a point at the end of the ruler, is a lower bound on the angular size of the Sun. The cylinder placed where it just blocks out the Sun will produce an angle that provides an upper bound on the angular size of the Sun.

Archimedes used the simplest estimate on the size of the Moon, namely that it is smaller than the Earth. This is obvious from observation of lunar eclipses. Archimedes then used the estimate of **Aristarchus** that the Sun is between 18 and 20 times the size of the Moon. Since Archimedes only required a safe upper bound, he overestimated this to 30 Moon diameters. Archimedes' final assumption was that the Sun's diameter was no larger than 30 Earth diameters.

Archimedes also took into account solar parallax, in other words, the fact that his estimate of the distance to the Sun was taken from a measurement on the surface of the Earth, while the actual distance that he was interested in is from the center of the Earth. Apparently, this is the first known example of solar parallax being taken into account.

Archimedes then concluded that the estimate of 0.36° would be a safe underestimate for the angular size of the Sun. Given the previous assumption that the diameter of the Sun is no larger than 30 times the diameter of the Earth, this meant that the orbit of the Sun was less than 30,000 Earth diameters. This led to the final estimate that the distance from the center of the Earth to the center of the Sun was less than 10,000 times the radius of the Earth.

Ilan Vardi

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Archytas of Tarentum

Flourished **(Italy), 4th century BCE**

Archytas is called the last of the Pythagoreans. He was a student of **Philolaus**, friend of **Plato**, and, according to some sources, teacher of **Eudoxus**. Archytas argued that things cannot exist independently of place. Consequently, if one travels to the supposed "edge" of the Universe, and there stretches out both arms, only one arm would continue to exist. As this seemed absurd, Archytas concluded that the premise is false and that the Universe must be unbounded. A crater on the Moon is named for Archytas.

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Argelander, Friedrich Wilhelm August

Born **Memel (Klaipeda, Lithuania), 23 March 1799**
Died **Bonn, Germany, 17 February 1875**

Friedrich Argelander was an observatory director who confirmed solar motion from stellar proper motions; he later produced the *Bonner Durchmusterung*. Argelander was the son of merchant and shipowner Johann Gottfried Argelander (whose father was Finnish) and Wilhelmina Dorotea Grünhagen. In 1823, Argelander married Maria Sophia Charlotte Courtan, and they had one daughter: Maria Wilhelmina Amalia.

Argelander studied astronomy in the University of Königsberg under **Friedrich Bessel**, completing his dissertation in 1822. Next year, he was appointed observator (associate professor) in Finland, at the University of Turku (Åbo in Swedish). The observatory in Turku had been founded in 1819, but its first observator, Henrik Johan Walbeck, died unexpectedly. During his time at Turku, Argelander observed positions of stars and comets, lunar occultations, and also aurorae borealis. He published five volumes of his observations and drafted a star catalog, especially from his 1827–1831 observations, known as the Turku catalog (*Catalogus Aboensis*). It was published in Helsinki in 1835. The *Catalogus Aboensis* contains over 10,000 precise observations of 560 stars whose positions in the sky change at least 1/5 of a second of arc per year. By comparing the positions Argelander measured with the positions of these stars measured in the beginning of the 18th century, he could determine their proper motions very precisely. His research was the most extensive and precise account of proper motions of stars by that time.

On the basis of his data, Argelander could determine if the Sun moves in relation to the surrounding stars. **William Herschel** had found the motion of the Sun based on a few stars but Bessel, using much broader and more precise data, had come to a negative conclusion. Argelander showed that the Sun does move, and the motion is directed toward an apex in the constellation of Hercules. Argelander published his study in the series of the Academy of Science of Saint Petersburg in 1837 and was awarded the great Demidov Prize of the academy for it. The work consolidated his position as one of the leading astronomers of his time.

The town of Turku was badly burned in 1827, and the university was transferred to Helsinki. In 1828, a chair of astronomy was created at the University of Helsinki, and Argelander was the first to be appointed. In cooperation with architect Carl Ludwig Engel, Argelander designed a new observatory in Helsinki. It was completed in 1834. The Observatory of Helsinki was built according to the newest demands of astronomy, and it became a model for many observatories, above all the Central Observatory of Russia in Pulkovo near Saint Petersburg, completed in 1839.

In 1836, a professorship in astronomy opened in the University of Bonn, and Argelander moved there in 1837. As there was no observatory in Bonn, he had one built. Before the completion of the new observatory in 1845, Argelander used small portable instruments for his observations. At that time, he created the first viable method to measure the variations of stellar magnitudes and thus funded the research on variable stars.

In 1852, Argelander started a decade-long work that since its completion has been known as the *Bonner Durchmusterung* (Bonn survey). It consists of an extensive star catalog and map, and contains all stars of the Northern Hemisphere brighter than the 10th magnitude. There are altogether 324,198 stars in the survey. The catalog and map have been used for over a century. The *Bonner Durchmusterung* was published in 1863.

The previous year, Argelander's student and assistant of many years in Bonn, **Karl Krüger**, was appointed professor of astronomy at the University of Helsinki. Before leaving Bonn, Krüger married Argelander's daughter who had been born in Helsinki.

In 1863, because of Argelander's influence, the German astronomical society *Astronomische Gesellschaft* was founded. It soon became one of the most important organizations in the field. On Argelander's initiative, the society launched in 1869 a cataloging project to observe as precisely as possible the positions of all the stars of the *Bonner Durchmusterung* brighter than the ninth magnitude. The work was divided among 13 observatories. Helsinki participated in the project under Krüger's lead. The 15-volume star catalog, known as *Katalog der Astronomischen Gesellschaft* (*AGK*), was completed in 1910.

Tapio Markkanen

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Argoli, Andrea

Born **Tagliacozzo, (Abruzzo, Italy), 1570**
Died **Padua, (Italy), 27 September 1657**

Andrea Argoli produced ephemerides and general works on astronomy. Argoli's father, Ottavio, was a lawyer. Argoli's son, Giovanni, would also become a lawyer and a precocious poet. Argoli studied in Naples but (he stated) without the help of a teacher. He also claimed to have studied privately in Padua with **Giovanni Magini**, teacher of mathematics and astronomy at the University of Bologna. Between 1622 and 1627 Argoli taught mathematics at the University La Sapienza in Rome. After **Benedetto Castelli** replaced him at the University La Sapienza, Argoli received support from Cardinal Biscia for 5 years. In 1632 Argoli was called to teach mathematics in Padua, where he taught until his death.

Argoli dedicated his ephemerides, published in 1623, to the Abbot of the Congregation of the Camaldolesi of Santa Mariå, another ephemerides, published in 1629, to Prince Filippo Colonnå, and two of his later works, *De diebus critici* and *Ptolomaeus parvus*, to Queen Christina of Sweden.

He had a good reputation as compiler of ephemerides based first on the Prutenic Tables and later on Tychonic observations.

Argoli was frequently cited in the correspondence between **Galileo Galilei** and Fulgenzio Micanzio, a Venetian friar friend of Galileo, as someone who had converted to the new astronomical theories, but no trace of his Copernicanism and his appreciation of Galilei can be found in Argoli's works.

In the *Astronomicorum libri tres* first published in 1629, Argoli presented his own system of the world. It was a geocentric system with the orbits of Mercury and Venus centered on the Sun; the Moon, Sun, Mars, Jupiter, and Saturn centered on the Earth like the scheme of **Martianus Capella**, but with the addition of the rotation of the Earth on its own axis. He also believed in the fluidity of the heavens and rejected the notion of solid spheres. Argoli's contention that the Earth rotates was supported by his belief in the world's spherical structure. Yet, despite this argument, he allowed for the stars to be spread out. He saw no necessary limit to the extension of the stellar region, though he remarked that those stars that we see must be at a finite distance. Argoli also claimed that the stars' unequal distance is directly perceptible. He penned several works on astrology, such as *De diebus criticis* and *Pandosion sphaericum*.

Argoli was a member of the Accademia Patavina dei Ricovrati (now Accademia Galileiana) in Padua and of the Accademia degli Incogniti in Venice. In 1638, the Venetian Republic gave him the title of Knight of Saint Mark, presented him with a gold chain, and raised his salary; by 1651 his salary was 1,100 florins.

Giancarlo Truffa

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Aristarchus of Samos

Born **Samos, (Greece), *circa* 310 BCE**
Died ***circa* 230 BCE**

Aristarchus as astronomer and mathematician has not always been given the credit he deserves by historians of science, even though he made two remarkable contributions to astronomy: a heliocentric solar system and estimates of the relative sizes and distances of the Sun and the Moon.

Aristarchus was a native of the island of Samos, and a contemporary of Euclid and **Archimedes**. Not very much is known of his early life or his work except for comments by later writers or his contemporaries. Only one of his works is extant, *Aristarchus on the Sizes and Distances of the Sun and Moon*, which is the oldest surviving mathematical work on determining the sizes of the Sun and the Moon in terms of the dimensions of the Earth and the relative distance to the Sun in terms of the distance to the Moon. He reportedly also wrote on vision, light, and colors. Aëtius tells us that Aristarchus was a pupil of Strato of Lampsacus, either in Athens or in Alexandria. A comment by

Ptolemy in *Almagest III* that Aristarchus observed the solstice of 281/280 BCE (the only date for Aristarchus we know for sure) and Archimedes' comments in the *Sand Reckoner* concerning Aristarchus' heliocentric theory of the motion of the Earth help to place his floruit. **Vitruvius** in his *De architectura* tells us that Aristarchus invented the "hemisphaerium" or "scaphe," a sundial with a hemispherical surface, and he is also identified as having invented the "discus in planitia," a dial with a horizontal shadow-receiving surface.

Among the ancient astronomers, **Philolaus** and Aristarchus stand alone in believing that the Earth moved in an orbit. Aristarchus proposed that it rotated about its axis and revolved around the Sun. Our most secure evidence for attributing the heliocentric hypothesis to Aristarchus comes from Archimedes' *Sand Reckoner*, where he explains to Gelon, son of Hieron II, King of Syracuse, how one might express very large numbers, and mentions Aristarchus: "Aristarchus of Samos … supposes that the fixed stars and the sun do not move, but that the earth revolves in the circumference of a circle about the sun, which lies in the middle of the orbit, and that the sphere of the fixed stars, situated about the same center as the sun, is so great that the circle in which the earth is supposed to revolve has the same ratio to the distance of the fixed stars as the centre of a sphere to its surface."

In *Aristarchus on the Sizes and Distances of the Sun and Moon*, Aristarchus applied geometry to the problem of determining the distances to the Sun and the Moon and their sizes relative to that of the Earth. Aristarchus made the following hypotheses (Heath, 1913):

(1) The Moon receives its light from the Sun.
(2) The Earth is like a point and is center to the sphere in which the Moon moves.
(3) When the Moon appears to us halved, the great circle that divides the dark and the bright portions of the Moon is in the direction of our eye.
(4) When the Moon appears to us halved, its distance from the Sun is less than a quadrant by one-thirtieth of a quadrant.
(5) The breadth of the (Earth's) shadow is (that) of two moons.
(6) The Moon subtends one-fifteenth part of a sign of the zodiac.

Hypotheses (1) and (2) are straightforward in their meaning. The implication of hypothesis (3) is that the angle formed at the Moon between the Earth and the Sun is a right angle when the Moon's terminator appears to be a straight line to an observer on the Earth, and of hypothesis (4) that the angle between the Moon and the Sun viewed from the Earth is 87°. Hypothesis 4, of course, requires an extremely difficult measurement, the actual value being about 89° 51′. As **Otto Neugebauer** and others point out, it is extremely difficult to determine the exact time of a straight terminator to within a day or two, which makes this approach observationally improbable. Hypothesis (5) claims the diameter of the Earth's shadow at the orbit of the Moon is 2 diameters of the Moon; the actual value is closer to Ptolemy's estimate of 2 and 3/5ths diameters of the Moon. Finally, hypothesis (6) claims that the angular diameter of the Moon is 2°, a value four times too big. From the first three hypotheses, Aristarchus determined that the distance of the Sun from the Earth is greater than 18 times, but less than 20 times, the distance of the Moon from the Earth. During a total solar eclipse it is observed that the Moon just covers the Sun; with this fact and the preceding conclusion, simple geometry gives the relative diameter of the Sun to be between 18 and 20 times the diameter of the Moon. Finally, from the hypothesis about the size of the Earth's shadow at the orbit of the Moon compared with the size of the Moon, he obtained that the Sun is between 19/3 and 43/6 (between 6.3 and 7.2) times the diameter of the Earth.

How do these numbers compare with current calculations? The actual distance to the Sun in terms of the distance to the Moon is 389, compared with the 18 to 20 times determined by Aristarchus. The actual size of the Sun compared to that of the Moon is 400, compared to 18 to 20 times the diameter of the Moon for Aristarchus. Both calculations are in error by roughly a factor of about 20. His determination of the size of the Sun ranges between 6.33 and 7.2 times the diameter of the Earth, with the actual value about 109 times. Using Aristarchus's numbers the size of the Moon is between 0.389 and 0.317 Earth diameters, with the actual value being 0.272, a value that is surprisingly comparable.

Although the values determined for the sizes and distances do not compare well with modern determinations, the methods set forth by Aristarchus were employed and modified by succeeding generations of astronomers, and marked a move to sophisticated methods of mathematical astronomy. Although he is credited with numerous other contributions, his hypotheses concerning the motion of the Earth and his theoretical approach to mathematical astronomy are truly remarkable.

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Aristotle

Born **Macedonia, (Greece), 384 BCE**
Died **322 BCE**

The ancient Greek worldview featured a central Earth surrounded by rotating spheres carrying the planets and stars; it persisted for some two millennia, from ancient Greece through medieval Islam to Renaissance Europe, and was largely the creation of the Greek philosopher Aristotle.

Aristotle's father was the personal physician of Amyntas II of Macedon, a poor land of unruly people at the northern edge of the Greek peninsula. At age 17, in 367 BCE, Aristotle left Macedon for Athens. There he entered **Plato**'s Academy, and stayed there for 20 years.

Philip II claimed the crown of Macedon in 359 BCE, gradually consolidated his control, and emerged as Athens' main opponent. Plato's death in 347 BCE, combined with an anti-Macedonian mood in Athens, saw Aristotle set sail across the Aegean Sea to Asia Minor. There he founded a new academy under the patronage of a local ruler, whose 18-year-old niece and adopted daughter Aristotle married. From his later description of the ideal age for marrying as 37 years for the man and 18 for the woman, it may be inferred that Aristotle's voluntary exile was not an unhappy one.

Aristotle returned to Macedon in 342 BCE to tutor the young Prince Alexander. Philip II completed his conquest of Greece in 338 BCE. In 336 BCE, following the assassination of his father, Alexander took the throne and Aristotle returned to Athens comfortably on the side of the victors. After Alexander's death, in 323 BCE, Aristotle again went into voluntary exile. He died a year later.

The standard interpretation of Aristotle's thought is that he began close to Plato's intellectual position and gradually departed from it. An alternative interpretation has Aristotle fundamentally a biologist interested in classification, and employing teleological and animistic, rather than mechanical, explanations. Also, and perhaps inevitably in pretelescopic times, Aristotle's astronomy was not one of meticulous observation followed by induction of theories, but rather the incisive and compelling deduction typical of geometry. A major strength of Aristotle's worldview lay in its completeness; every part followed logically from the other parts. From basic concepts in Aristotle's *Physica* (Physics) follow ideas developed in *De caelo* (On the heavens).

To have knowledge of something, or to have grasped the "why" of it, was, for Aristotle, to know the cause of the phenomenon. Aristotle classified causes into categories: the material cause, of what the object is made; the formal cause, the shape of the object; the efficient cause, who made it; and the final or purposeful cause, the object's use or purpose.

Aristotle's emphasis on the final cause, or purpose, underlies his otherwise confusing definition of motion. It was not solely change of position, called locomotion, but more broadly the fulfillment of potentiality. This sense of motion leads to a particular understanding of place, encompassing both motion and potential. Each of the four elements – earth, water, air, and fire – has its natural place. Moved from its natural place, each element has a natural tendency to return to its natural place.

This concept of place is not compatible with the existence of a void, because in a void there is no place. Thus the laws of natural motion cannot work in a void. To argue in this fashion, *reductio ad absurdum*, is to start with a seemingly plausible statement – the existence of a void – and then to deduce such absurd consequences from it that one is forced to conclude that the original statement cannot be true.

Also, projectile motion is not explicable in a void, because movement supportly requires constant contact between the moved object and the mover. The case of a thrown object raised a problem that would puzzle and plague generations of philosophers and scientists after Aristotle. Eventually, attempts to explain projectile motion would lead to the concepts of impetus and momentum and on to the concepts of inertia and a body remaining in motion until some force acted to stop it.

Another problem with motion in a void was why would motion ever cease, if there were nothing to stop it? Modern physics contemplates a body remaining at rest or in motion until acted upon by another force. For Aristotle, however, perpetual motion seemed absurd.

In the last book of *Physics*, Aristotle discussed the one form of locomotion that could be continuous. Locomotion was either rotatory or rectilinear or a combination of the two; only rotatory motion could be continuous. Furthermore, rotation was the primary locomotion because it was more simple and complete than rectilinear motion.

Aristotle's views on the organization and structure of the Universe are found in *De caelo*. All locomotion is straight, circular, or a combination of the two, and all bodies either are simple – composed of a single element, such as fire or earth – or are compounds. The element fire and bodies composed of it have a natural movement upward; bodies composed of earth have a natural movement downward (actually, toward the center of the Universe, and the Earth is thus at the center). Circular movement is natural to some substance other than the four elements. Aristotle infers that there is something beyond the region of the Earth, composed of a different material, of a superior glory to our region of the Earth, and also unalterable. This substance is more divine than the four elements, since circular motion comes before straight movement.

In Aristotle's two-sphere Universe there is a region of change with the Earth in the center, surrounded by water, with air and fire above. This region extends up to the sphere of the Moon. Beyond are the heavenly bodies in circular motion, in a realm without change. There is a separate set of physical laws for each of the two regions, since they are composed of different types of matter.

Aristotle's Universe is not infinite, he argued, because the Universe moves in a circle (as we can see with our eyes if we watch the stars). If the Universe were infinite, then it would be moving through an infinite distance in a finite time, which is impossible.

In another argument involving motion, Aristotle stated that bodies fall with speeds proportional to their weights. The statement is incorrect; bodies of different weights fall with the same speed. As a weak point in Aristotle's science, his comments on the speeds of falling bodies furnished an opening to critics, and the problem of falling motion became important in the development of the modern laws of mechanics.

The world was finite, and there was only one world. Were there more than one world – each world with a center as the natural place for earthy material to move to and a circumference for fire to move to – then the Earth could move toward any of the centers and fire toward any of the circumferences, and chaos would ensue.

Aristotle also argued that the heavens are unalterable. Not until the late 16th and early 17th centuries would observations of comets moving through the heavens and observations of novae (stars that flare up in brightness) reveal changes occurring in Aristotle's purportedly unalterable heavens.

Aristotle next showed that the heavens rotate and the Earth is stationary in the center. The shape of the heavens is spherical, the shape best suited to its nature, and the motion of the heavens is regular.

The composition of the stars was susceptible neither to observational nor to experimental inquiry until the middle of the 19th century, after the development of the science of spectroscopy. Aristotle, nonetheless, argued that the stars are composed of the same element as the heavens and are fixed to circles that carry them around. They do not move of their own effort.

Finally in his inquiry, Aristotle came to the Earth. At the center of the Universe, it is at rest. Its shape must be spherical, the shape it would take as its particles pack into the center. Also, the evidence of the senses indicates that the Earth is spherical: Eclipses of the Moon reveal that the Earth casts a circular shadow. The fact that different stars are seen from different parts of the Earth further demonstrates the spherical shape of the Earth.

Such observations were used more to persuade readers of the truth of the conclusions than as an aid in arriving at conclusions. Also Aristotle did not devise critical experiments with which to test his conclusions.

Whatever the shortcomings of Aristotle's worldview, for nearly two millennia it dominated much of the intellectual world. It was the astronomy of **Geoffrey Chaucer** and **Dante Alighieri**, and of the Catholic Church. Aristotle's astronomy remains an integral and important part of our intellectual heritage – of our literature, our art, our philosophy, and our very language and way of thinking.

Norriss S. Hetherington

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Aristyllus

Flourished **third century BCE**

Aristyllus was an early astronomer in the school of Alexandria. Little is known about him. He made astronomical observations during the first half of the third century BCE, and was probably a pupil of **Timocharis**.

Aristyllus and Timocharis are usually considered to have compiled the first true catalog of the fixed stars, in which stars are identified by numerical measurements of their positions. (In earlier lists, stars had been identified by descriptions of their locations, typically with respect to other stars and constellations.) The catalog is not extant. Indeed, while Aristyllus and Timocharis certainly amassed a set of numerical observations of star positions, it is not, strictly speaking, known whether these observations were assembled into a catalog or table. Probably fewer than 100 stars were observed, and the positions were reputedly of low accuracy. Observations by Aristyllus or Timocharis survive in **Ptolemy**'s *Almagest* for some 18 stars. The observations of Timocharis and Aristyllus were practically the only historical measurements of the positions of the fixed stars available to **Hipparchus**, who used them in combination with his own observations to discover the precession of the equinoxes.

Aristyllus is included in two lists of authors who wrote commentaries on the astronomical poem the *Phaenomena* by **Aratus**. (This poem enjoyed widespread popularity in Antiquity.) However Aristyllus' commentary is not extant. He is also included in a list of astronomers who wrote about "the pole," that is (in modern terms) stars close to the pole. In this context it might be noteworthy that three of the observations attributed to Aristyllus in the *Almagest* are of stars in the tail of Ursa Major. In *De Pythiae oraculis* (402 F) Plutarch includes Aristyllus in a list of astronomers who wrote in prose. However, most of the information about him comes from Ptolemy's *Almagest*, particularly the discussion of precession and its discovery by Hipparchus.

A. Clive Davenhall

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Arrhenius, Svante August

Born **Vik (or Wijk), Sweden, 19 February 1859**
Died **Stockholm, Sweden, 2 October 1927**

Chemist Svante Arrhenius was considered a child prodigy who reputedly taught himself how to read at the age of three. His father, Svante Gustaf Arrhenius, was a surveyor and estate manager for the University of Uppsala; his mother was Carolina Thunberg.

Arrhenius began his university education studying physics at the University of Uppsala. He felt that he was not receiving the best education, so he went to Stockholm to study under Professor Erik Edlund and to work on his doctorate. Arrhenius' dissertation, entitled *Recherches sur la conductibilité galvanique des électrolytes* (Investigations on the galvanic conductivity of electrolytes), was presented in 1884, but due mainly because his professors did not fully understand his work, the thesis and its defense received a low grade. In this treatise, Arrhenius began to develop his theory on the dissociation of ions in water, which led to his receiving the Nobel Prize for Chemistry in 1903. The mathematical formula for determining the effect of temperature on the reaction (velocity) rates of dissociated ions is now known as the Arrhenius equation.

In 1900, Arrhenius published his work *Lärobok I teoretisk elektrokemi* (Textbook of Theoretical Electrochemistry). In addition to his interest in chemistry, Arrhenius also studied physics and in 1903, he published his work on the physics of the northern lights in *Lehrbuch der kosmischen Physik* (Textbook of Cosmic Physics).

Arrhenius was offered a chair in the chemistry department at the University of Berlin in 1905, but, citing patriotic reasons, he declined the offer, desiring to stay in Sweden. The position of director of the Nobel Institute for Physical Chemistry in Stockholm was soon created for Arrhenius.

In addition to chemistry, Arrhenius contributed to physics, immunology, geology, cosmology, and climatology. In his 1906 book, entitled *Världarnas utveckling* (Worlds in the making), Arrhenius theorized that cool stars can collide and form nebulae from which new stars and planets are born and that life was spread *via* living spores scattered throughout the Universe carried by light pressure (panspermia). His *Stjärnornas öden* (Destiny of the stars) appeared in 1915. The latter two books went through several editions and translations into many languages.

Arrhenius has recently come into renewed prominence for a late nineteenth century calculation, the first, of the increase in the temperature of the Earth to be expected if the carbon dioxide content of the atmosphere increases. His estimate – a few degrees for a doubling of CO_2 as it then stood – is within the range of most modern calculations.

Arrhenius received several prestigious scientific honors and awards in addition to the Nobel Prize. In 1911, he was elected a fellow of the Royal Society and received its Davy Medal. He was awarded honorary degrees from Birmingham, Oxford, Cambridge, Greifswald, Groningen, Heidelberg, Leipzig, and Edinburgh universities.

Arrhenius was twice married and had two sons and two daughters. He is buried at Uppsala. A nearside lunar crater at latitude 55°.6 S, longitude 91°.3 W was named in 1970 by the International Astronomical Union to honor Arrhenius.

Robert A. Garfinkle

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Āryabhaṭa I

Born **(India), 476**

Āryabhaṭa I is the foremost astronomer of the classical age of India. He was born in 476 in Aśmaka, but later lived in Kusumapura, identified as the modern city of Patna. Nothing much is known about his personal life, except that he was a great and revered teacher. He is referred to as Kulapa (or Kulapati, vice chancellor), quite possibly of the Nalanda School. His work *Āryabhaṭīya* is the earliest preserved astronomical text of the scientific period of ancient Indian astronomy that bears the name of an individual.

Āryabhaṭa wrote at least two works on astronomy: (1) *Āryabhaṭīya*, a very well known work and (2) *Āryabhaṭa-siddhānta*, a work known only through references to it in later works. *Āryabhaṭīya* deals with both mathematics and astronomy and is noted for its brevity and conciseness of composition. It contains 121 stanzas in all and is divided into four chapters, each called a pāda. There exist a number of commentaries written in Sanskrit and other regional languages of India, and there also exist a large number of independent astronomical works based on it. Several English translations of *Āryabhaṭīya* have been published, including a critical edition of the text in Sanskrit accompanied by an English translation. Several critically edited commentaries on *Āryabhaṭīya* by earlier Indian astronomers, together with English translations, have also been published. *Āryabhaṭīya* was translated into Arabic around 800 as the *Zīj al-Arjabhar*.

The notable features of Āryabhaṭa's contributions are his acceptance of the possibility of the Earth's rotation, a set of excellent planetary parameters that may be based on his own observations, and a theory of epicycles. It may be noted that his theory of epicycles differs from that of **Ptolemy**. Ptolemy's epicycles remain the same in size from place to place whereas Āryabhaṭa's epicycles vary in size from place to place. Āryabhaṭa's contributions in mathematics include an alphabetical system of numerical notation, and giving the approximate value of Pi (π) as 3.1416. He also provided a table of sine differences, and formulae for sines of angles greater than 90°. He gave solutions to some indeterminate equations.

The other work, *Āryabhaṭa-siddhānta*, is known only through the references to it by other astronomers such as **Varāhamihira** and **Brahmagupta**. The astronomical methods and parameters in *Āryabhaṭa-siddhānta* differed somewhat from those in the *Āryabhaṭīya*, notably the reckoning of the day from midnight to midnight. Unfortunately, after Brahmagupta wrote the *Khaṇḍakhādyaka* based on the *Āryabhaṭa-siddhānta*, the original work was lost. Brahmagupta was a severe critic of Āryabhaṭa.

Narahari Achar

Alternate name

Āryabhaṭa the Elder

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Āryabhaṭa the Elder

Āryabhaṭa I

Āryabhaṭa II

Flourished **(India), *circa* 950–1100**

Āryabhaṭa II, the Hindu astronomer, is best known for his work entitled *Mahāsiddhānta* or *Āryasiddhānta*. It has been established indirectly that he lived and worked around the 10th century. In order not to confuse him with the well-known astronomer **Āryabhaṭa**, who lived in the fifth century, he is known as Āryabhaṭa II or the Younger.

The *Mahāsiddhānta* or *Āryasiddhānta* is an astronomical compendium based on the orthodox tradition of *Smṛti*s (passages from Vedic literature). The treatise written in Sanskrit consists of 18 chapters and 625 *śloka*s (verses). The first 12 chapters deal with mathematical astronomy. Detailed derivations are presented on topics such as the mean and true longitudes of the planets, eclipses of the Sun and the Moon, the projections of eclipses, the lunar crescent, and the heliacal rising and settings of planets, including some calculations on conjunctions of planets as well as planets with stars. The remaining six chapters of the *Mahāsiddhānta* form a separate section called the *Golādhyāya* (On the sphere) where topics on geometry, geography, and algebra are discussed with reference to celestial astronomy. In Chapter 17, for example, shortcuts are provided for determining the mean longitudes of the planets. In Chapter 18, under the section called *Kuṭṭakādhyāya*, Āryabhaṭa II discusses the topic of the solution of indeterminate equations of the first degree. He improves upon earlier methods and suggests a shorter procedure.

In his work, Āryabhaṭa II also touches upon several arithmetical operations such as the four fundamental operations, operations with zero, extraction of square and cube roots, the rule of three, and fractions. To represent numbers, he adopts the famous *kaṭapayādi* system of letter numerals. This practice does not conform to the method followed by some of his predecessors, who used the well-known *bhūta saṃkhyā* system of word numerals.

The text does not say anything about the year and place of Āryabhaṭa II's birth, nor does it give any other personal information. In recent years several scholars have tried to establish an approximate period in which he lived based on the cross-references to his work made by other contemporary and younger scholars. D. Pingee believed that Āryabhaṭa II's treatise was written between 950 and 1100, and G. R. Kaye concludes that he lived before **Bīrūnī** (973–*circa* 1050). However, B. Datta disagrees with the date given by Kaye and argues that Āryabhaṭa II must have lived much later. Many recent articles on this subject state that his main work was written in 950. **Brahmagupta** (born: 598) leveled several criticisms on Āryabhaṭa I but not on Āryabhaṭa II. S. Dikshita has therefore put forward the argument that places Āryabhaṭa II later than Brahmagupta. Another important point noted is that Āryabhaṭa II tried to remove some discrepancies involving the criticism of Brahmagupta on Āryabhaṭa I. Thus Dikshita assigns him a date around śātavāhana śaka 875, which corresponds to 953. This corroborates the opinions of other historians as well.

A. Vagiṣwari

Alternate name

Āryabhaṭa the Younger

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Āryabhaṭa the Younger

Āryabhaṭa II

Asada, Goryu

Born **Kitsuki, (Oita Prefecture), Japan, 1734**
Died **Osaka, Japan, 1799**

Goryu Asada played an important role in reforming the Japanese calendar and in inspiring Japanese astronomers to move from traditional Chinese to contemporary Western instrumentation and techniques. He was the fourth son of Keisai Ayabe, who was a Confucian scholar and physician in the *Kitsuki* domain. At birth, Goryu was given the name Yasuaki. He educated himself in astronomy and medicine, and took over his father's practice in 1767 as official physician appointed to the *daimyo*, though Yasuaki's passion was studying astronomy and calendar making. In 1772, when the *daimyo* refused to release him from duties so that he could pursue his astronomical interests, Yasuaki left illegally from his domain.

He fled to Osaka, where he changed his name to Goryu Asada, and took up the study of astronomy and calendar science with a passion, while practicing medicine to make ends meet.

Asada gained a high reputation for his brilliance in calendar studies, including the development of his own calendar system. Much of his work was based on scientific ideas that were slowly and secretively creeping into the closed Japan of the Edo era (1603–1867). Many young and talented scholars who would later exert influence, such as **Yoshitoki Takahashi**, Shigetomi Hazama, and Tachu Nishimura, became Asada's pupils in what was called the *Senjikan* academy. In 1795, he was invited by the shogunate to join a project to reform the *Horyaku Reki* calendar, but he declined because of ill health. Instead, he recommended his best pupils, Takahashi and Hazama; both ended up going to Edo in Asada's place. Although Takahashi was the main representative, it was the combined effort of the Asada school that led to the *Kansei* calendar reform of 1798. This was the first calendar reform in Japan that was based on Western concepts of celestial movement. Because of poor health and perhaps overdrinking, Asada died the following year.

Asada made several observational "firsts," being the first Japanese astronomer to measure the Sun's rotation by observing sunspots. However, it is his steadfast use of both rational and empirical methods, and the inspiration he gave his students within that methodological framework, that gives lasting significance to his work. Asada stood in the middle of a time when trends were changing in Japan, trends that would culminate in major reforms of the 19th century. Dismayed with crude observational methods and outdated celestial models, members of the Asada school were encouraged to develop accurate observational techniques as well as creative mathematical modeling. Often, this work stood in direct opposition to what had become the rigid bureaucratic structure of the Tsuchimikado family in Kyoto that contained titular professionals.

Asada's school actively encouraged learning Western models and modes of astronomical observation, replacing traditional Chinese instruments with modern equipment and leading to more observational precision and accuracy. While not fully understanding all the written material obtained or translated from Western sources, Asada inspired his students to conduct systematic observations in order to empirically test models used in calendar reckoning.

The lack of historical background in the development of Japanese science as well as the associated political and social upheaval in the West were each a curse and a blessing. On the one hand, they were a handicap to acquiring full understanding of all theoretical concepts being developed. On the other hand, they allowed a certain intellectual freedom from debates regarding human positioning within the cosmos that characterized so much thinking in Europe. As a result, Asada and his students often developed unique if not wholly original solutions to calendrical problems.

Asada is sometimes seen as making the only original achievement in the history of astronomy in Japan, discovery of the so-called *Sho-Cho* (*Hsiao-ch'ang*) law. This law dealt with variability in the length of the tropical year, of obvious concern in the development of an accurate calendar (Earlier Chinese calendar scholars in both the Sung and the Yuan dynasties had discussed variation in the tropical year.) Asada sought to reconcile observed data obtained from Western sources with available historical sources and his own observations. Although not as elegant as **Pierre de Laplace**'s work based on perturbation theory, and perhaps somewhat simplified in its algebraic formulation, its "goodness-of-fit" to observed data at the time is quite remarkable.

Steven L. Renshaw and *Saori Ihara*

Alternate name

Yasuaki

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Ascham [Askham], Anthony

Flourished **England, 16th century**

Englishman Anthony Ascham's *A Lytel Treatyse of Astronomy* (1552) is one of the earliest astronomy books written in English. A chronological list appears in the selected references below.

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Ashbrook, Joseph

Born **Philadelphia, Pennsylvania, USA, 4 April 1918**
Died **Weston, Massachusetts, USA, 4 August 1980**

As a member of the *Sky & Telescope* staff from 1953 until his death, and its editor from 1964, Joseph Ashbrook augmented the high editorial and scientific standards established by its founders, **Charles Federer** and his wife Helen Federer. Ashbrook joined *Sky & Telescope* after receiving a Ph.D. from Harvard University in 1947 and teaching at Yale University (1946–1950) and Harvard University (1950–1953). His academic teaching career was compromised by a speech impediment, but as an editor he taught by example through his dedication to clear and accurate writing.

Ashbrook's longest-lasting scientific contribution was the determination of the rotation period of Mars, which was incorporated in the *American Ephemeris and Nautical Almanac* from 1960 to 1983. He is also remembered for his discovery, in 1956, of periodic comet 47P/Ashbrook–Jackson. Ashbrook loved to compute things, almost obsessively. As a result, during his tenure *Sky & Telescope* was awash with reductions of reader observations of lunar eclipses, transits of Mercury, young Moons, eclipsing stars, and other phenomena. Ashbrook had a lifelong interest in variable stars, and his knowledge of them was encyclopedic. The same was true of lunar and planetary astronomy, which throughout most of his career was a backwater for professionals. All these interests allied him closely with the amateur community. Ashbrook clearly helped usher in the modern era of professional–amateur collaboration.

Yet it was as a purveyor of astronomical curiosities and arcana that Ashbrook is most remembered. His bimonthly feature "Astronomical Scrapbook" was a staple in *Sky & Telescope* from 1954 to 1980; most of his columns were collected in a book. Ashbrook brought a rare perspective to astronomical history since he was as familiar with German and French literature as he was with English literature. He read everything and remembered it; his home was lined with books.

Ashbrook was a member of the American Astronomical Society and the International Astronomical Union. A minor planet, (2157) Ashbrook, and a crater near the Moon's south pole, were named in his honor. As Clark Chapman stated in his remembrance of the second editor of *Sky & Telescope*: "Astronomy has lost a fine man, a rigorous scientist, a gifted educator, and a skilled craftsman in the increasingly important field of scientific communication."

Leif L. Robinson

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Ashraf: al-Malik al-Ashraf (Mumahhid al-Dīn) ˁUmar ibn Yūsuf ibn ˁUmar ibn ˁAlī ibn Rasūl

Born ***circa*** **1242**
Died **(Yemen), 22 November 1296**

al-Ashraf ˁUmar, the third of the Rasulid sultans in Yemen, was a prolific scholar who wrote a number of works with astronomical content. The date of Ashraf's birth is uncertain, and only a few details of his life are recorded. In 1266/1267, Ashraf commanded a military mission for his father to the northern town of Ḥajja and later became governor of al-Mahjam along Wādī Surdud in the coastal region of Yemen. His father, al-Muẓaffar Yūsuf, appointed him coregent in 1295. Four months later Ashraf ˁUmar succeeded him on the throne. In the same year Malik al-Ashraf visited al-Dumluwa and later the coastal town of Zabīd. He reigned in Yemen for about 2 years until his death in 1296. He was buried in the Ashrafiyya school he had founded in Taˁizz. Ashraf left behind six sons and two daughters, both married to sons of Ashraf's brother, Mu'ayyad Dāwūd, who succeeded him on the throne.

In contrast to his father's reign, which was long and prosperous, Ashraf's own reign was short-lived and without major historical significance. His minor importance for the political history of his realm is counterbalanced by his considerable contribution to science.

Ashraf wrote some 13 treatises on a variety of scientific fields including medicine, genealogy, agriculture, veterinary medicine, astronomy, and astrology. He made several astronomical instruments, among which were astrolabes. For the sake of brevity, only the extant contributions to astronomy will be mentioned.

In the Metropolitan Museum of Art in New York, an Islamic astrolabe is preserved that is signed by ˁUmar b. Yūsuf b. ˁUmar b. ˁAlī b. Rasūl al-Muẓaffarī, *i. e*., Ashraf, dated 1291, and measures 15.5 cm in diameter. It is competently made without being particularly sophisticated, but some unusual features make it unique: on the rete, there is a scale for the lunar mansions; and on the back, there is astrological information using planetary symbols that had been adopted by Muslims from Greek sources. The plates are engraved for latitudes in Yemen and Hejaz and were constructed using the tables presented in Ashraf's treatise on the construction of the astrolabe, not by using geometrical construction.

Ashraf's treatise on the construction of the astrolabe as well as other instruments, entitled *Muˁīn* (or *Minhaj*) *al-ṭullāb fī al-ˁamal bi-'l-asṭurlāb*, is preserved in two manuscripts in Cairo and Tehran. The sultan mentions there the extensive treatise on spherical astronomy and astronomical instruments written by **Marrākushī**. Ashraf's treatise contains an explanatory text on the construction of an astrolabe, diagrams of the different parts, and tables for the construction of, for example, the altitude circles and the azimuth circles for specific latitudes in Yemen and the Hejaz, and tables of the shadows-lengths and the altitude of the Sun at the beginning of the afternoon prayer. The two star catalogs use the degree of the ecliptic with which the star culminates and the radius of the day circle of the star and not, as more usual, the ecliptic or equatorial coordinates.

The star pointers on the rete of Ashraf's astrolabe do not correspond with the star positions mentioned in his treatise. Nevertheless, the connection between instrument and text is definite. In particular, the back of the astrolabe made by Ashraf, and the illustration of the back of an astrolabe in his treatise, are virtually identical. It is indeed rare that we find references in the medieval literature to specific instruments that have survived to this day.

In his treatise, Ashraf deals not only with the astrolabe but also with horizontal sundials, the water clock, and the magnetic compass. At the end, the text is supplemented with notes by two of Ashraf's teachers. The section on the sundial contains tables of coordinates for marking the seasonal hours on the shadow traces of the zodiacal signs computed for latitudes in Yemen and the Hejaz, using 23° 30′ for the obliquity of the ecliptic. These tables are of the same kind as those of **Ḥabash** and Marrākushī, who use 23° 51′ and 23° 35′, respectively. The section on the magnetic compass describes the construction and use of a floating compass.

Ashraf explains the making of the compass bowl, with the rim and the scales engraved there, and the preparation of the magnetic needle, which is inserted crosswise in a stalk. He continues with the determination of the meridian under bad weather conditions, using the magnetic compass, and the use of this information to find the *qibla*, the sacred direction of Islam to Mecca, which one should know to fulfill several Islamic religious obligations such as the five daily prayers. This is the first time the magnetic compass is mentioned in a medieval astronomical treatise and also the first time that it is used as a *qibla*-indicator.

The notes by two of his teachers inform us that they have inspected four or six astrolabes, made by Ashraf himself, which are most accurate and skillful. They testify to Ashraf's excellence in the construction of astrolabes and give him permission to make whatever he likes in the way of astrolabes. Additionally, they mention two water clocks made by Ashraf. So it is probable that Ashraf also made other instruments, such as the sundials described in his treatise.

Ashraf's third contribution to the science of the stars is his extensive collection of astronomical texts and related subjects entitled *Kitāb al-Tabṣira fī ˁilm al-nujūm*, preserved in Oxford. It contains 50 chapters on astrology and astronomy, timekeeping, and an almanac. In essence, it represents an introduction to medieval astronomy that includes basic zodiacal and planetary astrology as well as a range of information on timekeeping systems. The subjects covered include the zodiac, the course of the Sun, the course of the Moon, planets, fixed stars, eclipses, astrolabes, lunar mansions, calendar systems, determination of the *qibla*, weather, medicinal regimes for each season, the agricultural calendar, and systems of numbers. Most of the chapters deal with astrology, but there are also lengthy chapters on timekeeping including tables displaying the solar altitude and longitude of the horoscope as functions of the solar longitude for each seasonal hour of the day. Another table gives the geographical coordinates of different localities. The *Tabṣira* draws on a wide variety of earlier texts and authors; among others, Dorotheus and **Kūshyār ibn Labbān** are mentioned.

In Chapter 32, Ashraf documented the seasonal reckoning of changes in nature and human activities. This almanac is the earliest known treatise of this kind written in prose about Yemen and was probably compiled in about 1271. It is arranged in tabular form. Each page contains daily data for half of the solar Christian month (beginning in October). Each bears information on the entry of the Sun in each sign, the hours of daylight and darkness, and the shadow-lengths for the beginning of the midday and afternoon prayers (for the beginning and midpoint of each month). For the *anwā*ʾ (certain stars used for weather prognostication), Ashraf relied upon Ibn Qutayba. The information in the almanac derives both from the general almanac tradition and from knowledge of local practices and folklore.

Ashraf was not a great genius but a teachable pupil and a versatile scholar. His astronomical treatises bear a great deal of information about earlier texts. The uniqueness of his astronomical work is due in part to the vicissitudes of history. It is Ashraf who, for the first time, documented in tabular form the yearly astronomical and agricultural events in medieval Yemen. It is Ashraf's description of the magnetic compass that, for the first time, proves that the magnetic compass was used as a *qibla*-indicator, though the author makes no claim to have invented the device. And it is a real windfall that one of the sultan's astrolabes and his treatise on the construction of the astrolabe are preserved.

Petra G. Schmidl

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Aston, Francis William

Born **Birmingham, England, 1 September 1877**
Died **Cambridge, England, 20 November 1945**

English physicist William Aston is best known for the invention of the mass spectrograph to measure accurate masses of the atoms of individual isotopes of many elements. He is known within astronomy particularly for the demonstration that one helium atom is about 0.1% less massive than four hydrogen atoms, thus making clear the potential of hydrogen fusion as a stellar energy source.

Aston was rare among scientists in that he chose to work both inside and outside academic circles, and through this choice he achieved great success. He began his early education at Harborne Vicarage School and Malvern College, and then entered Mason College, Birmingham, as a student of physics and chemistry in 1894. During his time at Mason College, Aston had the opportunity to study with the eminent physicist **John Poynting** and other notable scientists of the day.

In an interesting career choice, Aston took a position in the laboratory of a brewery, which excited his interest in the techniques and tools of evacuating pressure vessels. He took this position in spite of his having the early career success of publishing the results of his studies of the optical properties of organic acids. (This work was sponsored by the Forster Scholarship he received in 1898.) His interest in vacuum science led to Aston receiving a scholarship to the University of Birmingham in 1903, and he returned to academic life to study the properties of discharge tubes.

His work at the University of Birmingham brought Aston to the attention of Sir J. J. Thomson (1856–1940). It resulted in an offer to work as Thompson's assistant at the prestigious Cavendish

Laboratory in Cambridge. At the laboratory, Aston worked on studies of positive rays, *i. e.*, accelerated atoms or molecules carrying positive charge, and searched for evidence that there was more that one isotope of neon.

With the exception of the period of World War I, Aston remained at Cambridge for the remainder of his career. During the war, he supported the effort by working on enhancing airplane fabrics and coatings with the Royal Aircraft Establishment in Farnborough. At the end of the war he returned to the Cavendish Laboratory and restarted his work on the separation of the isotopes of neon.

Aston's study of neon isotopes led directly to his development of the mass spectrograph, which could determine the mass of an isotope to better than one part in thousand. Using his invention, Aston discovered that the masses of other isotopes could be expressed as multiples of the mass of oxygen, which became known as the "Whole Number Rule." He eventually discovered 212 isotopes (more than two-thirds of the stable ones now known).

Aston received numerous awards for his work including honorary doctorates and several academic medals. Among his more prestigious awards were the fellowship of the Royal Society and the Nobel Prize in Chemistry (1922); he accepted the latter with the lecture entitled "Mass Spectra and Isotopes." Aston's Nobel citation recognizes his invention of the mass spectrograph and the discovery of the "whole number rule."

Aston wrote several books, and his work on the mass spectrometer was published in the most prestigious journals of the day. In addition to being a gifted academician, Aston was a musician and a sportsman. He played several instruments and enjoyed a number of diverse sporting activities.

Scott W. Teare

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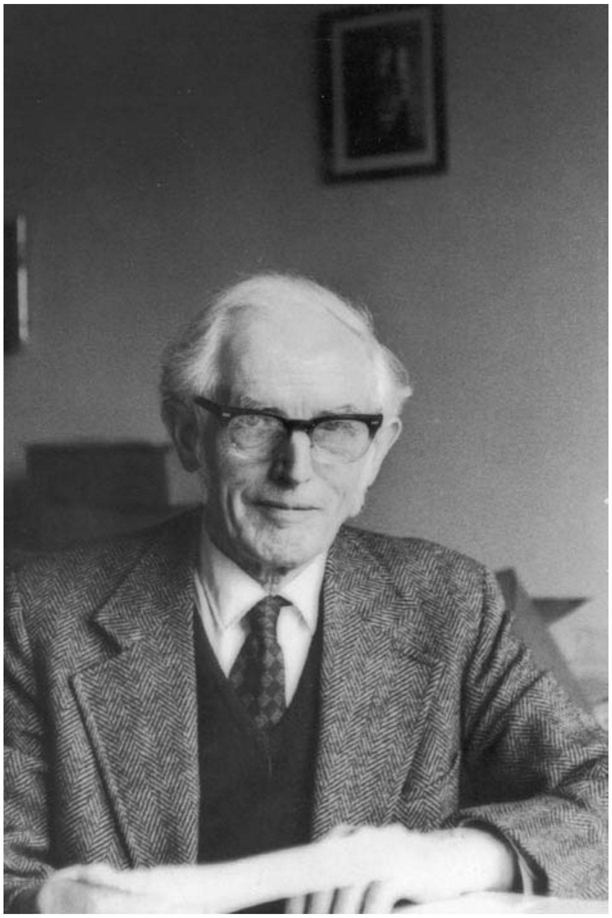
Atkinson, Robert d'Escourt

Born **near Rhayader, (Powyss) Wales, 11 April 1898**
Died **Bloomington, Indiana, USA, 28 October 1982**

Robert Atkinson is best known for his contributions to stellar energy theory.

Atkinson's childhood education was at Manchester Grammar School. Attending on an Open Scholarship, he graduated from Hertford College, Oxford, in 1922 with a first-class degree in physics. Under the supervision of **Adolph Lindemann** he worked as a demonstrator and researcher at the Clarendon Laboratory for 4 years. In 1926 Atkinson received a Rockefeller Traveling Fellowship, which he used to study in Göttingen with James Franck. He attained his D. Phil. in 1928 in physics with minors in mathematics and astronomy. After teaching briefly at the Technische Hochschule in Berlin, he took a professorship of physics at Rutgers University in New Jersey, USA, in 1929. Atkinson remained at Rutgers University for 8 years, once turning down a job offer from Princeton University. In 1937, he accepted the post of chief assistant at the Royal Observatory, Greenwich, England, and for a time he worked at Aberdeen Proving Ground in Maryland, USA under **Edwin Hubble** – one of several times he was sent abroad during World War II. In 1964, Atkinson retired from Greenwich and took a professorship at Indiana University. He became emeritus in 1979, and died in Bloomington in 1982.



Atkinson was named fellow of the Royal Astronomical Society [RAS] in 1937, and served as secretary from 1940 to 1941. He was a founding member of the Institute (later Royal Institute) of Navigation, becoming a fellow in 1953. He served as president of the British Astronomical Association in 1960–1961 and 1961–1962. Atkinson received the Eddington Medal at the RAS in 1960 for his work on fusion in stars. He was awarded a Royal Commission Award to Inventors in 1948. In 1977, the International Astronomical Union named a minor planet (1827) Atkinson in his honor.

In the late 1920s, Atkinson worked with **Fritz Houtermans** on the application of **George Gamow**'s barrier penetration theory to stellar interiors. Their work showed that Gamow's theory allowed for nuclear synthesis of the elements as a source of stellar energy, a possibility suggested earlier by **Arthur Eddington** and others, but never put on a firm physical basis. They calculated reaction rates for proton capture by light nuclei, and showed that heavier elements could be created by a sequence of two-body interactions. This dismantled the widely held objection that transmutation in stellar interiors would require a spectacularly improbable simultaneous meeting of four or more particles, and eventually helped pave the way for the acceptance of fusion as the energy source for stars. The process they described was a series of cyclic nuclear reactions that used heavier elements as catalysts: once there were sufficient amounts of certain heavy elements, helium production could be a regenerative process. The fundamentals of their theory were strikingly similar to the cycles described by **Hans Bethe** and **Carl von Weizsäcker** in the late 1930s.

Atkinson and Houtermans published their work in 1929 in the *Zeitschrift für Physik*, but it received little attention since their calculations rested on the still dubious assumption that the majority of matter in stars was hydrogen. In 1931 and 1936, after a high hydrogen content came to be better accepted, Atkinson recast and extended their work in papers titled "Atomic Synthesis and Stellar Energy" in the *Astrophysical Journal*. Here he showed the steep dependence of reaction rates on temperature, which was consistent with Eddington's theory of a small range of stellar core temperatures in the main sequence and inconsistent with **Edward Milne**'s proposal of a constant energy generation rate throughout a star. Atkinson argued that his work suggested that the brightest stars would have a short lifetime (roughly 10^8 years for a B star), and used this to support the "short" timescale universe, in contradiction to the "long" timescale of 10^{11-12} years espoused by **James Jeans**. Finally, Atkinson contended that the cosmic abundances of the elements could be accounted for largely by the processes in stellar interiors, and that white dwarf stars did not need any nuclear source of energy to maintain their luminosity.

Atkinson's move to Greenwich in 1937 largely halted his work on stellar physics. He later said he regretted taking the chief assistant position. The observatory was "a little like a factory" and provided little opportunity to pursue his scientific interests that were not directly related to pragmatic astronomical matters. The war in Europe provided him with plenty of work, however, and he found himself degaussing ships and calculating ballistics until 1943. He then worked on photometry with Hubble until 1946, when he was sent to Europe to find out what the observatories there needed to recover from the war. (His fluency in German was invaluable.)

After the war Atkinson's astronomical work focused on instrumentation and positional astronomy. He designed a major improvement on the transit circle, and developed a theory of, and measurement techniques for, the problem of telescope tube flexure. He brought attention to systematic errors from the 1930/1931 Eros Campaign caused by tube flexure in the Greenwich Astrographic, which led to a revision of the value for the solar parallax. Atkinson also invented novel techniques for filming solar eclipses, and persuaded the International Astronomical Union to redefine the instantaneous pole of celestial coordinates to remove its dependence on the rotation axis of the Earth. His final years at the Royal Observatory were spent overseeing the institution's move to Herstmonceux Castle in Surrey.

After retiring as chief assistant, Atkinson returned to stellar physics and began work on general relativity. He taught courses at Bloomington on relativity, binary stars, and positional astronomy. While there, he designed a unique "standard time" sundial that remains a landmark on campus. His personal research was investigating general relativity in the framework of Euclidean geometry.

Atkinson's papers are at Indiana University, Bloomington, in excellent condition, and well organized. The finder's guide is online and includes a list of most of his published papers. The American Institute of Physics has an extensive oral history interview with Atkinson recorded in 1977. They also hold correspondence between him and figures such as **Arthur Eddington** and **Henry Norris Russell**.

Matthew Stanley

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Augustine of Hippo

Born **Tagasta (Souk-Ahras, Algeria), 354**
Died **Hippo (near Annaba, Algeria), 430**

The son of a pagan father and Catholic mother, Saint Augustine had a good classical education though, perhaps unique amongst classical philosophers, he failed to learn Greek, which he disliked intensely, to any more than a rudimentary level. At the age of 19 he joined the Manicheans, a Christian church that had adopted the Persian cosmology in which the structure and history of the Universe was based on the perpetual struggle between light (good) and darkness (evil). To the Manicheans, Christ was the representative of light. During this period Augustine achieved recognition for his philosophical work and was appointed professor of rhetoric at Milan. At the age of 28 he converted to Catholicism and at the same time began reading **Plato** and the Neoplatonic philosophers, Plotinus and Porphyry. Although he personally challenged such elements of Neoplatonic cosmology as the divinity of the stars, the stamp of Augustine's authority established a favorable attitude to Platonic cosmology within medieval Christian culture. He was baptized in 387, and in 391 he was ordained a priest in Hippo, near Carthage in what is now Tunisia. Augustine was appointed bishop of Hippo in 395 and spent the rest of his life there.

In his two great works, *Confessions*, composed around 397, and *City of God*, written in 410, Augustine established himself as the foremost theologian of the Catholic church. His argument that the newly christianized Roman state was the representative of the Kingdom of God on Earth gave the church a firmly conservative identity as the ally, rather than opponent, of the political order. This convenient relationship was to be the basis of church–state relations through to the early modern period.

Augustine's contribution to the history of astronomy is based on his definitive denunciation of astrology, the result of which was to both confirm the separation of astrology from astronomy for many Christians and provide a rationale for Christian opposition to astrology to the present day. Augustine had studied astrology during his time as a Manichean and found he had no theological objection to it, because astrologers neither offered sacrifices nor prayed to spirits for assistance in their divination. However, his conversion to Catholicism resulted in a substantial change of heart. He now regarded God as the only supreme power in the Universe, possessing direct and immediate authority over the entire natural world. He tackled astrology in two levels: First, Augustine argued that it was incompatible with Christianity, and, second, he pointed out illogicalities in its reasoning.

In the *Confessions* Augustine claimed that to argue that God's authority could be exercised *via* the stars caused theological offense, for it both limited God's power to intervene directly in human affairs and implicated Him in the stars' less worthy decisions. It also absolved human beings from responsibility for their own actions and, ironically, pushed that guilt onto God who, according to Augustine's version of astrological logic, would have instructed the stars to cause men to sin in the first place. To pursue this argument to its logical conclusion, God was the cause of sin. He widened his attack in the *City of God*, dealing at length with the issue of twins and the question of how two babies born at the same time could have different lives. Augustine also tackled the problem of the apparent contradiction between the astrally determined fate inherent in an astrology of individual births on the one hand and the assumption of free will inherent in the astrological election of auspicious moments to begin new enterprises on the other. He questioned whether astrology applied to worms or trees and challenged the belief that the rise of the Roman Empire had been astrologically determined rather than the result of God's favor. Augustine also dealt with the claim that astronomical alignments functioned as signs rather than causes, pointing out that even astrologers who argue that the stars signify events nevertheless talk as if they cause them, and hence are still impinging on territory rightly reserved for God. In Book VII he went on to ridicule the flawed logic behind stellar divinities, although in Book V he had also sought allies among the pagans, appealing to them on the grounds that, if astrologers ascribed power over human affairs to the stars, they were challenging the authority of pagan deities as well as the Christian God.

Even though Augustine regarded the reasoning behind astrology as profoundly flawed, he had no doubt that it worked, although he changed his mind on how. In the *Confessions* he argued that it appeared to work because of chance. Thus an astrological forecast appeared to be right in the same way as a volume of poetry might fall open at a page meaningful at that moment. In the *City of God* Augustine took a firmer line, claiming that evil spirits fed correct predictions to astrologers.

Augustine's attack on astrology should be seen as an attempt to despiritualize the Universe at the same time as he constructed a new moral cosmology, saving religious authority for God alone. His criticism of secular, liberal education and advocacy of Scripture as the ultimate source of truth also left little room for classical astronomy, leaving the Genesis creation story as the basis of Catholic cosmology. Although he singled out **Thales**' prediction of the eclipse of 585 BCE for praise, his philosophy is clearly dominated by a combination of Scripture and Neoplatonism, which between them taught that all truth is based on faith and abstract reason rather than evidence or observation. While Augustine's separation of astrology from astronomy was therefore of great significance, the effect of his teaching was to retard the development of astronomy in the Christian world until the 17th century.

Nicholas Campion

Alternate name

Aurelianus Augustinus

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Aurelianus Augustinus

➤ **Augustine of Hippo**

Autolycus

Born **Pitane (Candarli, Turkey), *circa* 360 BCE**
Died ***circa* 290 BCE**

Two of Autolycus's three books have come down to us and are considered the oldest original treatises on mathematics that have survived (in translation) in their entirety.

Little is known about the life of Autolycus, and even the dates associated with him are not clear. It is generally believed that he was older than Euclid, and it is known that he taught the philosopher Arcesilaus, founder of the Middle Academy. Autolycus was a contemporary of **Aristotle** and is generally considered to have been primarily an astronomer. The only known specific piece of information on his life comes to us from Diogenes Laertius, who reports that Autolycus was accompanied by Arcesilaus on a trip to Sardis.

The two of Autolycus' treatises on astronomy that have survived are *De orto* (On risings and settings) and *De sphaera mota* (On the moving sphere). They survived in large part due to their inclusion in *Little Astronomy*, which was an early compilation similar to **Ptolemy**'s later *Great Collection* or *Almagest*. *De sphaera mota* deals generally with great circles, including meridian circles and latitudinal parallels. It also deals with visible and invisible areas produced by a light source shining on a rotating sphere. In this book Autolycus used the same form of writing as Euclid, including propositions and proofs.

De orto is largely a book on observational astronomy. Autolycus is known to have relied heavily on **Eudoxus** for his astronomical ideas and was a supporter of Eudoxus' theory of homocentric spheres (a series of embedded spheres that held the stars and planets, and that all rotated on an axis parallel to the Earth's). Autolycus attempted (unsuccessfully) to explain the variability in brightness of Venus and Mars within the context of this theory and also attempted to rectify the theory with the concept of eclipses, again with no real success. It is interesting to note that there is no evidence that Autolycus, despite his work with spheres, had any knowledge of spherical trigonometry. However, his propositions indicate that there should have been some knowledge of that type at the time. Many scholars conjecture that there must have been a contemporary standard textbook on the subject that has been lost to history. Some suggest, simply through the process of elimination, that the author of this unknown textbook was Eudoxus, but not a shred of proof exists to support that claim.

A crater on the Moon is named for Autolycus.

Ian T. Durham

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Auwers, Arthur Julius Georg Friedrich von

Born **Göttingen, (Germany), 12 September 1838**
Died **Berlin-Lichterfelde, Germany, 24 January 1915**

Arthur von Auwers's primary interest for most of his life was in preparing extremely accurate catalogs of the positions of stars.

Auwers's father was Gottfried Daniel Auwers, master of the horses at the University in Göttingen, while his mother was Emma Christiane Sophie (*née* Borkenstein). He lost both parents while still a child and was sent to finish schooling at the gymnasia at Schulpforta at the age of about 12.

Auwers's interest in astronomy originated in his early school years; in 1862, he published a work on **William Herschel**'s catalog of nebulae and clusters that was based on observations Auwers made, starting in about 1854. Auwers studied astronomy in Göttingen and Königsberg and was appointed assistant at the observatory in Königsberg in 1859. During this period he made observations of comets, asteroids, and variable stars in addition to nebulae. In 1862, Auwers received a doctoral degree from Königsberg for a thesis in which he computed the orbits of Sirius and Procyon assuming an invisible companion in each case. **Friedrich Bessel** had speculated, as early as 1842, that minor variations in the proper motion of these stars were due to invisible companions. The discovery of the companion of Sirius by **Alvan Graham Clark** confirmed Bessel's hypothesis in 1862. However, the companion of Procyon was not observed until **John Schaeberle** found it in 1896.

In November 1862 Auwers married Marie Henriette Jacobi (1837–1915) and departed for Gotha where he worked with theoretician **Peter Hansen** at the private observatory of the Duke of Mecklenburg. During his 4 years with Hansen, Auwers determined parallaxes for a number of stars. In 1866, Auwers received an appointment as astronomer at the Berlin Academy, and it was there that his most important work was completed.

The opportunity that Auwers seized, on his arrival at Berlin, deserves some explanation. Both before and after becoming Astronomer Royal, the British astronomer **James Bradley** had concentrated his observing activity on measuring the positions of stars. His observations are the earliest trustworthy position measurements now available. But Bradley never reduced his observations, so that at the time of his death in 1762, the manuscript of his observations was not directly usable. Nevertheless, two friends of Bradley arranged to have the manuscripts set in type and published in book form at Oxford University; the second and final volume appeared in 1798, 36 years after Bradley's death. **Heinrich Olbers** acquired copies of these books and provided them to Bessel in Königsberg. Bessel realized the value of a long homogeneous series of observations made with the same instruments at the same location, and undertook the reduction of Bradley's observations. The resulting catalog, titled *Fundamenta Astronomæ pro anno 1755*, was published in 1819 and revolutionized positional astronomy.

In the 50 years between the appearance of *Fundamenta Astronomæ* and Auwers' arrival at Berlin, enormous progress was made in positional astronomy, both on observational work and on techniques of reducing those observations. Furthermore, systematic differences had become apparent in comparisons of the work of various astronomers, and it was no longer clear that *Fundamenta Astronomæ* could be relied upon. There were, for example, serious discrepancies between the right ascensions of *Fundamenta Astronomæ* and those determined by **Urbain Le Verrier**. Thus, in 1868, Auwers undertook a completely fresh reduction of Bradley's observations. He worked from Bradley's original manuscripts, rather than the published volumes, used all of Bradley's observations, and discovered many of Bradley's errors that Bessel had overlooked in addition to errors in Bessel's own work. Where there were questions that could be resolved by further observations, Auwers undertook those observations personally. He extended the work to include observations made by Bradley from locations other than Greenwich, and eventually included some observations by **Stephen Groombridge** and **Giuseppi Piazzi** to fill in gaps in Bradley's observational records. Using all these resources Auwers eventually republished Bradley's catalog of 3,268 stellar positions for the epoch 1755.0. Auwers then extended these positions by rigorous mathematical calculations to form a new catalog for the epoch 1865.0. A similar catalog of fresher observations carried out at Greenwich, and in Berlin, between 1854 and 1867 was reduced rigorously to the epoch 1865.0. Comparison of these two catalogs at epoch 1865.0 provided precise proper motions for the 3,268 stars. The revised Bradley catalog was published in three volumes between 1882 and 1903.

With the revised Bradley data available, Auwers then reanalyzed all available observations, spanning a period of several hundred years, for 36 bright stars that became the fundamental framework to which all subsequent measures of other stars could be referred. His work formed the basis for the fundamental catalog of the Astronomische Gesellschaft known as the *AGK1*. In his 1888 presidential address at the time the Royal Astronomical Society's Gold Medal was presented to Auwers, **James Whitbread Glaisher** reviewed in considerable detail both the steps in this lengthy and detail-laden process of data reduction and the advances achieved by Auwers through this work

Auwers' work in Berlin was interrupted by three scientific expeditions. In 1874 he traveled to Luxor, Egypt, to observe the transit of Venus. He traveled to Punta Arenas, Chile, in 1882 to observe the second transit of Venus of the 19th century, obtaining data on both expeditions for an exact determination of the Sun's parallax. The results of these two expeditions filled six volumes. Another expedition took Auwers to the Cape of Good Hope in 1889 to observe an opposition of the minor planet (12) Victoria with David Gill, again for the purpose of making an accurate determination of the solar parallax.

In 1881, Auwers was honored by his election as president of the Astronomischen Gesellschaft. In addition to the Royal Astronomical Society Gold Medal, which he received in 1888, Auwers' British colleagues presented him a portrait of James Bradley in 1912, the same year that Auwers was elevated to hereditary nobility.

Auwers had three sons, including the noted chemist Karl Friedrich von Auwers. A crater on the Moon is named to honor Arthur von Auwers.

Ednilson Oliveira

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Auzout, Adrien

Born **Rouen, France, 28 January 1622**
Died **Rome, (Italy), 23 May 1691**

Adrien Auzout is known primarily for his work in astronomy, mathematics, and physics, with his main contribution to astronomy being his efforts in the development of the filar micrometer and telescopic sights. Auzout's father was a local government official in the court of Rouen and possibly also the Viscount of Rouen. There appears to be no record of Adrien's schooling, but it was not unusual for the son of an aristocrat to have received his education by private tutors. The evidence is not clear whether he was a Catholic or not. His first notable scientific work came in 1647, when he created a vacuum inside another vacuum in order to prove that the pressing weight of a column of air causes the mercury in a barometer to rise.

In a letter in 1665, Auzout wrote that he believed the heliocentric universe hypothesis of **Nicolaus Copernicus** was not absurd nor a false philosophy and that those ideas were not in conflict with Biblical teachings. He felt the Bible was not designed to teach people about the sciences, in particular physics and astronomy.

In the same year Auzout was instrumental in convincing King Louis XIV to create an observatory in Paris and to establish a French scientific society consisting of professional scientists. The following year, Auzout became one of the founding members of the Académie des sciences when it received its official government sanction and was a founding member of the Royal Observatory. On 22 March 1667, the site for the Paris Observatory was purchased, and construction of the observatory was soon under way. Auzout was also involved in the negotiations to bring Italian astronomer **Giovanni Cassini** to Paris in 1668.

The first telescope micrometer, used for measuring the angular distance between two celestial objects, was developed in the late 1630s by English astronomer **William Gascoigne**. Gascoigne used threads from a spider web for the instrument's crosshairs. (He also invented the knife-edge micrometer.) In 1666, Auzout, unaware of Gascoigne's work, developed a filar micrometer with the assistance of the astronomer **Jean Picard**. The device employed a stationary and a movable wire used for making measurements through a telescope. Auzout refined and improved his micrometers between 1666 and 1671. In his first micrometer, he moved the wire by hand and later used a threaded screw for more accurate movement of the wire. In 1667, Auzout developed the idea of placing the cross wires at different planes so that the line of sight between them could be assured by the observer. His invention was used for both astronomical measurements and land surveying. In the 1700s, filar micrometers were used for the first time for determining the exact position of lunar features.

A dispute over a flawed translation of the works of **Vitruvius** by the physician and architect Claude Perrault – another founding member of the Académie des sciences – appears to be the primary reason for Auzout's resignation from the Académie in 1668. Shortly after this dispute erupted, Auzout left to live in Rome.

A lunar nearside crater at latitude 10°. 3 N, longitude 64°. 1 E, was named for Auzout by the International Astronomical Union in 1961.

Robert A. Garfinkle

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Avempace

➤ **Ibn Bājja: Abū Bakr Muḥammad ibn Yaḥyā ibn al-Ṣā'igh al-Tujībī al-Andalusī al-Saraqusṭī**

Averroes

➤ **Ibn Rushd: Abū l-Walīd Muḥammad ibn Aḥmad ibn Muḥammad ibn Rushd al-Ḥafīd**

Avicenna

➤ **Ibn Sīnā: Abū ˁAlī al-Ḥusayn ibn ˁAbdallāh ibn Sīnā**

Azarquiel

➤ **Zarqālī: Abū Isḥāq Ibrāhīm ibn Yaḥyà al-Naqqāsh al-Tujībī al-Zarqālīˁ**

B

Baade, Wilhelm Heinrich Walter

Born **Schröttinghausen, Nordrhein-Westfalen, Germany, 24 March 1893**
Died **Göttingen, Lower Saxony, (Germany), 25 June 1960**

German–American astronomer Walter Baade is remembered for three major contributions to observational, extragalactic astronomy: the recognition of two basic population types of stars, the characterization (with **Fritz Zwicky**) of supernovae as a distinct class of event with energy derived from the collapse of a normal star to a neutron star, and the optical identification (with **Rudolph Minkowski**) of Cygnus A and other strong radio sources, which led to the "colliding galaxy" theory of radio sources.

Baade studied at Münster and Göttingen universities, where he received his Ph.D. in 1919 and became the scientific assistant to the mathematician Felix Klein. Baade was later appointed research assistant at the Hamburg Observatory, with access to a 1-m reflector, the largest telescope in Germany. In addition to working on a traditional program focused on comets and asteroids, Baade measured variable stars, recorded spectra of nebulae, and read research reports about the 60- and 100-in. reflectors at Mount Wilson, California. He dreamt of studying variable stars and globular clusters with the largest telescopes in the world.

As a German in the postwar years, Baade could not follow in the footsteps of Henri Chrétien, who secured a fellowship to work on the 60-in. telescope the year after it opened (1909). Then in 1926, on an expedition to photograph a mid-Atlantic solar eclipse, Baade met **Harlow Shapley**, the director of the Harvard College Observatory. Shapley used his influence at the International Education Board to obtain a 1926–1927 Rockefeller Fellowship for Baade, who spent part of his fellowship year at Mount Wilson. There he impressed the staff with his observing skill as he conducted research that led to a paper on the Baade (later the Baade–Wesselink) method of determining the radius and therefore absolute magnitude of pulsating variable stars especially Cepheids. Baade also collaborated with Wolfgang Pauli on a theoretical paper explaining the curved shape of comet tails as a result of the solar wind.

His growing reputation earned Baade a promotion to *Observator* (the equivalent of assistant director and next in line for the directorship) at the Hamburg Observatory. Among his research interests, he identified novae so bright that he gave them the name "Hauptnovae," his forerunner of the term supernovae. Baade also went on another solar eclipse expedition, this time to the Phillipines with **Bernard Schmidt**, the eccentric, one-armed Estonian optician of the Hamburg Observatory. On the long sea voyages they discussed the need for a wide-field, coma-free reflector telescope for survey searches for variable stars, galaxies, nebulae, and planets. Schmidt later used a spherical mirror with a thin corrector plate to build the first of the wide-field camera designs that bear his name.

Baade continued to long for the large telescopes, clear weather, and the good seeing of southern California. In 1931, he was invited to become a permanent member of the staff at the Carnegie Institution of Washington [CIW] Observatory, and moved to Pasadena, California, with his wife Johanna (called Hanni by her friends, and Muschi by Baade). At Mount Wilson, Baade amassed an incomparable collection of fine astronomical photographs as he experimented with emulsions, filters, auxiliary lenses, and focusing, guiding, and development techniques. **Milton Humason** and **Edwin Hubble** drew on Baade's work, though he never collaborated with them on publications.

Baade's own research program focused on stellar populations, globular clusters, cepheid variables, and understanding stellar evolution. He remarked to colleagues that while the study of cosmology, the nature of the Universe in the large, might be hopeless, cosmogony, the origin of the Universe was quite accessible to solution. Baade worked quietly, avoiding the publicity that Hubble constantly sought. He was most at home in the domes of the big telescopes, where his insistence on observing in a coat and tie did not hinder his mastery of the temperamental mirror of the 100-in. or the occasionally sticky mounting of the 60-in. telescope.

Baade brought to Pasadena a photograph Schmidt had taken with his new wide-field camera in Hamburg. As a result, the Palomar Observatory project included an 18-in. Schmidt camera as the first working telescope at the new site. With Zwicky, a Caltech physicist, Baade extended his earlier explorations of supernovae. Zwicky searched with the Schmidt telescope for supernovae; Baade would follow up with studies of their light curves with the bigger telescopes on Mount Wilson. Their 1934 paper, still much cited, contained four key ideas: supernovae are completely distinct from ordinary novae; the energy source is the collapse of a normal star to a neutron star; some of the energy goes into accelerating cosmic rays; and the Crab

Nebula and S Andromeda (SN 1885A) are examples of supernovae. The collaboration collapsed when Zwicky, who notoriously had trouble with colleagues, claimed that he had introduced the idea of the Schmidt camera, accused Baade of stealing credit and reneging his part of the collaboration, and called Baade a Nazi sympathizer.

Others found Baade a model colleague – witty, enthusiastic about a wide range of astronomical questions, and a born raconteur. Despite a marked limp from a congenital hip defect, Baade enjoyed walking with colleagues, taking advantage of the pauses while he rested his leg to drive home his points. A perfectionist in his writing as in his observations, he published little, but a staff member at the Carnegie Institutions commented that despite the paucity of articles, Baade "is one of the most prolific of our staff members. He 'publishes' his data by conversations in his office with the world's astronomers."

During World War II, when the other CIW astronomers joined war efforts at Caltech or elsewhere, Baade, who had never applied for American citizenship, was restricted to Pasadena and Mount Wilson as an enemy alien. With unlimited access to the big telescopes, he undertook a task considered beyond the capability of the 100-in. Hooker telescope, then the largest in the world – resolving stars in the nucleus of the Andromeda galaxy and its companions M32 and NGC 205. Using red-sensitive plates, special precautions to stabilize the temperature of the primary mirror, a dilute ammonia bath to increase the sensitivity of the plates, and taking advantage of nights of optimum seeing and the wartime brownouts in the Los Angeles basin, Baade guided for 4 hours on a faint off-axis guide star magnified 2,800 times. His patience and diligence paid off. **Joel Stebbins** called Baade's resolution of stars in the nucleus of M31 and its companions a "pure steal" from the prestige of the nearly complete 200-in. telescope. The images were published as specially developed enlargements bound into an issue of the *Astrophysical Journal*.

Baade's article generated a flood of ideas about the types of stars constituting galaxies. Baade's own contribution, in two important articles of 1944, was the articulation of two distinct population types: The populations were distinguished by their locations, colors of the brightest stars, and morphology of their Hertzsprung–Russell [HR] diagrams. Population I, in the disk of the Milky Way and other spirals, has its brightest stars blue and an HR diagram with a main sequence and supergiants. Population II, in the halo of the Milky Way, in globular clusters and in elliptical galaxies, has its brightest stars red and an HR diagram with giants and a horizontal branch. Later work showed that the Population I stars also are systematically younger and contain a larger component of heavy elements. This elegant formulation, expanded when more data was available and later the focus of a conference in Rome in 1957, was one of Baade's great contributions to the understanding of stellar populations.

After the war, Baade took on two doctoral students, Allan Sandage and Halton Arp, from the new astrophysics program at Caltech and served as a mentor to **Nicholas Mayall**, **Olin Wilson**, and others. He took many of the test plates for the commissioning of the 200-in. telescope at Palomar, including some that Hubble used in his announcements about the telescope.

When the Palomar telescope entered service, Baade attempted to resolve RR Lyrae stars in M31, a task that calculations showed should have been possible with the 200-in. telescope. The failure to image the stars, together with increasing knowledge of the absolute magnitude of the globular cluster giants he had resolved in 1944, led Baade to postulate a new distance scale, replacing the one that had been used since Hubble's 1924 proof that Andromeda was an extragalactic system. Baade's paper, presented in 1952, famously doubled the distance scale and age of the Universe. Confirmation was available on the spot at the General Assembly of the International Astronomical Union in Rome, because **David Thackeray** had resolved the RR Lyrae stars in the Large Magellanic Cloud with a smaller telescope in South Africa, and, sure enough, they were about 1.5 magnitudes fainter than expected.

At Palomar, Baade made extensive studies of the Crab Nebula and its central star, discovered the polarization of light in the jet of M87, and worked with Rudolph Minkowski to provide optical identifications of radio sources, including Cygnus A and Cassiopeia A. Little of Baade's work on the 200-in. telescope was published. He remained a perfectionist, and the possibilities of the telescope were still to be explored.

Baade retired from the CIW in 1958, then taught a course on "The Evolution of Stars and Galaxies" at Harvard and observed on the 74-in. telescope at Mount Stromlo. He told his students and colleagues that his failure to become an American citizen was absent-mindedness, but he remained German – his dog Li was notoriously unfriendly to anyone speaking any language but German – and in 1959 returned to Germany to accept the Gauss Professorship at Göttingen. Walter Baade died from complications after an operation on his hip.

Cecilia Payne-Gaposchkin edited and published Baade's Harvard lectures, which were for many years a standard text on stellar and galactic evolution. The Carnegie Institution has named one of the new 6.5-m telescopes at Las Campanas, with a beautifully figured *f*/1.25 mirror and superb optics, the Walter Baade telescope.

Ronald Florence

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Babcock, Harold Delos

Born **Edgerton, Wisconsin, USA, 24 January 1882**
Died **Pasadena, California, USA, 8 April 1965**

American laboratory and stellar spectroscopist Harold D. Babcock produced very high-quality ruled gratings for spectrometers and used them (in collaboration with his son, **Horace Babcock**) to map out the magnetic fields of the Sun and stars with great precision. Babcock was the son of the owner of a general store and received his early education in the public schools of Wisconsin. He completed an additional 4 years of secondary school in Los Angeles after the family moved there in 1896, acquiring a good grounding in science, languages, and the arts. It was during this time that he also began private experimental work, particularly radio, and developed a fascination that led to his enrolling in electrical engineering at the University of California at Berkeley in 1901. Babcock quickly decided, however, that his principal interests lay in physics – especially spectroscopy – and he obtained a BS degree (the only university degree he obtained) in 1906. From 1906/1907, he served as an assistant at the National Bureau of Standards, married Mary Henderson in 1907, and in 1908 briefly taught physics at Berkeley.

In February 1909, Babcock accepted an invitation by **George Hale** to join the staff of the Mount Wilson Observatory, California–as a physicist, not an astronomer–where he remained for the rest of his scientific life. His son, Horace Welcome, was born in 1912. In later years, the two were both staff members at the Mount Wilson Observatory and collaborated on many projects even after the elder Babcock's retirement.

Babcock was a spectroscopist of first magnitude at a time when laboratory astrophysics was being cultivated by Hale as vital for interpreting the Sun and stars. His work required developing techniques for ruling very high-resolution diffraction gratings; he also used interferometers in laboratory studies. Babcock's earliest investigations dealt with Zeeman effect measurements for iron peak elements whose lines are well-represented in the solar spectrum, especially vanadium, chromium, and iron. As a by-product of this work, he redetermined the charge-to-mass ratio for the electron (*i. e.*, the value of e/m) independent of other, nonspectroscopic measurements (*e. g.*, the Thomson cathode ray deflection experiment and the Millikan oil drop technique). Babcock also studied pressure broadening and developed techniques for producing large format, very high-resolution diffraction gratings. In this last activity, which continued after his official retirement in 1948, he was a principal contributor to the quick successes of the Palomar 5-m telescope.

In 1914, Babcock and **Charles St. John** began a protracted study of laboratory atomic spectra with the intent to provide a comprehensive list of solar spectral line identifications using high-resolution gratings and, more significantly, the Fabry–Perot interferometer. Their technique for stabilizing emission arcs was adopted by the International Astronomical Union [IAU], and their measurements became one of the standard sets used by the IAU to establish standard wavelengths. Babcock and St. John were joined by **Charlotte Moore**, L. M. Ware, and E. F. Adams in the revision of the Rowland atlas of the solar spectrum. In addition to extending the infrared cutoff for the list from 7,730 Å to 10,218 Å, their 1928 publication listed identifications for over 22,000 lines. Subsequent studies by Babcock and Moore extended the known solar lines to 2,935 Å in the ultraviolet and to 13,500 Å in the infrared.

In 1927, during this study of the solar spectrum, Babcock and Gerhard H. Dieke reported the discovery of two very weak terrestrial absorption bands near the O_2 A-band at 7,596 Å. Designated A′ and A″, these consisted of narrow lines and appeared to be similar to the A band. William F. Giauque and Herrick Lee Johnston soon showed, in 1929, that they are due to isotopic molecules, $^{18}O - {}^{16}O$ and $^{17}O - {}^{16}O$ with abundances of about 4×10^{-3} and 10^{-4}, respectively. Raymond T. Birge and Babcock used the molecular band constants to determine the mass ratio for these isotopes, the first discovered in nature, and showed that the scale used for mass needed revision. Subsequently, **Harold Urey** announced discovery of deuterium, and the field of isotope chemistry and spectroscopy was opened. In separate work, Babcock interferometrically studied the auroral and night sky light at 5577.350 Å, achieving a resolution better than 0.035 Å (his quoted upper limit for the line width) and permitting its identification as a forbidden transition of neutral oxygen.

Although Babcock engaged in solar physics throughout his career at Mount Wilson, his most important work was done in collaboration with his son after he retired from the scientific staff. Their invention of the solar photoelectric magnetograph changed the study of stellar magnetism. Babcock's last original research work dealt with measurements of the solar polar field, successfully detecting a reversal of the dipole component of the field.

Babcock's work did not go unrecognized. He was elected to the National Academy of Sciences, shared the Pacific Division Prize of the American Association for the Advancement of Science with Giauque and Johnston (1927), and was awarded the Bruce Medal of the Astronomical Society of the Pacific (1953). He received an honorary LL.D. from Berkeley (1957). The lunar crater Babcock is named in his honor. The minor planet (3167) Babcock was named in his honor and also that of his son.

Steven N. Shore

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Babcock, Horace Welcome

Born **Pasadena, California, USA, 13 September 1912**
Died **Santa Barbara, California, USA, 29 August 2003**

Horace Babcock was the son of **Harold Babcock**; the two shared many scientific interests, collaborated on some important studies of the Sun and instrument design, and received several of the same honors (though never together).

Horace Babcock was born in Pasadena, where his father was on the staff of the Mount Wilson Observatory (1908–1948). Babcock attended Caltech as an undergraduate, completing his B.S. in physics in 1934. He obtained a Ph.D. in astronomy from the University of California at Berkeley in 1938, studying the dynamics of M31 using Lick long-slit spectra. His thesis established the trailing nature of the spiral pattern and considerably extended the earlier studies of **Vesto Slipher**, **Frances Pease**, and **Ernst Öpik**.

Babcock's spectra showed a large rotation speed for M31 very far from its center, implying a mass and mass-to-luminosity ratio for the galaxy much larger than what **Edwin Hubble** and others were finding. The thesis, which appeared as a *Lick Observatory Bulletin*, therefore was greeted with some distrust, and he never worked again in extragalactic astronomy. Yet the publication is now often cited as a pioneering work in the detection of dark matter.

Babcock remained briefly at Lick Observatory as an assistant after his degree. From 1939 to 1941, he was a postdoctoral fellow at MacDonald Observatory. During World War II, he worked first at the Massachusetts Institute of Technology on radar and related problems as a staff member at the Radiation Laboratory (1941/1942) and then moved to Caltech to work on rocketry (1942–1945).

In 1946 Babcock joined the staff of the Mount Wilson and Palomar observatories. He remained there for the rest of his scientific career, becoming assistant director (under **Ira Bowen**) from 1957 to 1964, and then serving as director from 1964 until his retirement in 1978. One of the first changes he made in observatory policy was the decision to allow women astronomers to apply for and be assigned time at Palomar Mountain. His administrative career coincided with the extension of the observatory operations to the Southern Hemisphere, with the addition of the Carnegie Southern Observatory at Las Campanas in Chile.

The Mount Wilson Observatory had been organized by **George Hale** around the study of solar magnetic fields and, especially given the elder Babcock's deep interest in such work, it is not surprising that a single physical phenomenon, the Zeeman effect, formed the kernel of Babcock's scientific career. Whether dealing with the analysis of the spatial and temporal structure of the resolved solar magnetic field or the analysis of large-scale ordered fields in stars, he directed his energies, and those of many members of the observatory staff, toward the study of cosmic magnetism. The younger Babcock was a gifted instrument designer, and the photoelectric solar magnetograph, invented with his father, was the most significant innovation in solar instrumentation since Hale' s invention of the spectroheliograph. The device used an electro-optical ammonium–dihydride phosphate retarding plate followed by a Nicol prism to separate the polarization states, switched at 120 Hz, upstream from the spectrograph slit followed by a grating with a resolution of 600,000 lines/in. at the Fe I 5250.216 Å line. The device produced an image by scanning the Sun's disk and recording the local polarity with comparatively high-spatial resolution using photomultipliers that separately recorded the signal from the alternate wings of the Zeeman-split polarized line. Although the initial measurements were limited to relatively low sensitivity, the maps provided the first synoptic view of the global organization of the solar magnetic field with a resolution of about 10 G (a shift of about 0.08 mÅ) and provoked much of the modern work on stellar dynamos.

The magnetograph showed, for the first time, that the photospheric magnetic field is organized into filaments, rather than a global dipole, which extend into the chromospheric network and ultimately into the corona. The general field is a weak dipole at most times. The dynamo that drives the surface field must be rooted deep in the convection zone. None of these insights would have been possible without the imaging capabilities of the magnetograph. The design has been extended in the last decade to all four Stokes parameters (providing both linear and circular components), and the chromospheric field can be measured now using the Hanle effect. Still, the work ultimately rests on the basic Babcock design. The original Babcock magnetographic maps also presaged the era of space weather forecasts, when such images produced at high spatial and temporal resolution with full vector magnetographs can be used to predict the onset of coronal mass ejections and flare activity.

Babcock also invented a photoelectric autoguider for large astronomical telescopes (1948) and later adapted the technology to a device for measuring astronomical seeing by observing Polaris through crossed Ronchi gratings imaged onto a photomultiplier (1963), a basic technique used in many later site surveys to monitoring seeing automatically.

Interestingly, although his research publications appeared to end with his assumption of the directorship – evincing a complete absorption in the scientific administration of a vibrant institution – on retirement Babcock reemerged as a leading advocate for adaptive optics techniques and was recognized as one of the guiding spirits in this rapidly evolving technology. His 1953 paper is now considered one of the pioneering works in the field.

Applying a photographic adaptation of the magnetograph to stellar spectroscopy, in 1946 Babcock discovered a large longitudinal magnetic field in the main sequence chemically peculiar A star 78 Vir (HD 118022). This was not only the first direct detection of a global magnetic field in a nonsolar type star but also the first measured large-scale, stable ordered field in a star other than the Sun. It immediately created a new area in stellar astrophysics. Babcock' s idea was to use these extremely sharp-lined stars (presuming their low rotational broadening was an inclination effect rather than intrinsic) to search for strong fields using an adaptation of the solar magnetograph. Although there were some speculations, especially by **Patrick Blackett**, about how such fields might arise, the discovery was serendipitous, and the association with the chemically peculiar stars largely coincidental at first. The fields were both ordered and enormous, up to tens of kilogauss – global magnetic fields as strong as those typically observed in sunspots. With the first success, new discoveries quickly followed.

Almost immediately, Babcock reported the reversing magnetic field in HD 125248, a known spectrum variable included by **Armin Deutsch** in his 1947 analysis of the Ap stars. (A curiosity is that this study, which neither makes use of nor acknowledges the magnetic observations, appeared in the same volume of the

Astrophysical Journal.) Babcock separated the variations into three basic types, ostensibly denoted by a prototype: alpha (α^2 CVn), periodic and reversing; beta (β CrB), reversing but not definitively periodic; and gamma (γ Equ), constant or fluctuating but neither periodic nor reversing. Although known since the discovery of periodic photometric variations in α^2 CVn early in the days of photoelectric photometry, there were no indications of magnetic fields associated with these stars. Babcock assumed a solar analog for the magnetic field generation, even with such short timescales. It was **Martin Schwarzschild** (1950) and Deutsch (1958) who developed the oblique-rotator hypothesis to explain the magnetic field and spectrophotometric variations. Interestingly, it was Babcock's discovery of the crossover effect, when the polarity of the magnetic field reverses due to rotation (so the combined Doppler shifts of the intensified line cancel the magnetic displacement), that provided the vital clue to the oblique-rotator model that has since proved so successful. Anticipating later work on line formation in strongly magnetized atmospheres, Babcock realized that the Zeeman effect can delay the onset of saturation in transitions with large Landé factors, thus altering the curve of growth and affecting abundance determinations by such methods. Later work quantified this, including polarized radiative transfer, but Babcock's physical insight was also important in determination of elemental abundances in the chemically peculiar A stars.

Babcock also discovered the strongest field yet detected in a main sequence star, a 34 kG longitudinal field in HD 215441, a silicon star also called Babcock's star. Subsequent observations, by Babcock and later, in the mid-1960s, by G. W. Preston at Lick Observatory, discovered the transverse component of the Zeeman effect in the resolved lines of HD 215441 and other strong field stars; the study of such stars has developed rapidly since the 1990s with the use of Charged-Couple Devices [CCDs].

Among numerous honors, Babcock was awarded the Draper Prize of the National Academy of Sciences (1957) for his work on solar magnetic fields, the Bruce Medal of the Astronomical Society of the Pacific (1970), the Eddington Medal (1957) and the Gold Medal (1970) of the Royal Astronomical Society, and the Hale Prize of the American Astronomical Society (1992) for his broad contributions to solar physics.

Steven N. Shore

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Babinet, Jacques

Born **Lusignan, (Vienne), France, 5 March 1794**
Died **Paris, France, 21 October 1872**

Jacques Babinet's major work was devoted to the diffraction of light. He used diffraction to measure wavelengths more accurately than before, and did theoretical work on general diffraction systems. He was the son of Jean Babinet, mayor of Lusignan, and Marie-Anne Félicité Bonneau du Chesne, daughter of a lieutenant general. He married Adelaide Laugier; they had two sons.

Babinet began his studies at the Lycée Napoléon, then at the École Polytechnique, where he later became an examiner. He left the École Polytechnique in 1812 to enter the Military School at Metz. For some time he was attached to the Fifth Regiment of Artillery, but at the Restoration he left the army and took up teaching. He was professor of mathematics at Fontenay-le-Comte, then professor of physics at Poitiers and, from 1820, at the Lycée Saint-Louis, Paris. From 1825 to 1828 Babinet delivered a course of lectures on meteorology. In 1838 he succeeded **Félix Savary** at the Collège de France. Two years later, Babinet was elected to the Académie des sciences as a member of the General Physics Section.

Babinet's major scientific contribution was in optics, although his contributions to science include the other branches of physics and mechanics. Babinet's theorem states that there is an approximate equivalence between the diffraction pattern of a large system and that of the complementary system, which is opaque where the original system is transparent and *vice versa*. He showed an interest in the optical properties of minerals, developing new instruments for the measurement of angles and polarizations, especially Babinet's compensator, a double quartz wedge used in the study of elliptically polarized light. He was the first to suggest (1829) that the wavelength of a given spectral line could be used as a fundamental standard of length, an idea eventually used in metrology in 1960. He constructed a portable goniometer, improving upon E. L. Malus' device.

Babinet's interests in physics transcended laboratory work and included all phenomena in nature. Thus, the study of meteorology, particularly meteorological optics, occupied much of his career. He began his work in this field with an investigation of interference phenomena produced in the atmosphere: rainbows and "coronas," or colored rings surrounding the Sun or the Moon under certain weather conditions. Later work included modifications of the theory of atmospheric refraction and a study of polarization of skylight, especially the mysterious existence of neutral or unpolarized points in the sky. He also constructed a hygrometer. In mechanics, he improved the valves of the air pump, attaining a very high vacuum.

Babinet also achieved considerable fame as a popularizer of science, explaining natural phenomena to lay audiences in public courses and in articles in popular journals. Speaking about geology, mineralogy, astronomy, and meteorology, Babinet exhibited his rare ability to reduce complex phenomena to an easily comprehensible level.

Christian Nitschelm

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Bache, Alexander Dallas

Born **Philadelphia, Pennsylvania, USA, 19 July 1806**
Died **Newport, Rhode Island, USA, 17 February 1867**

United States Coast Survey Superintendent Alexander Bache was involved in establishing several major American observatories of the 19th century. Under his supervision, the Coast Survey was a major employer of astronomers at a time when other sources of employment for American astronomers were sparse. See also his solar observations with **Stephen Alexander**.

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Backhouse, Thomas William

Born **Sunderland, England, 14 August 1842**
Died **Sunderland, England, 13 March 1920**

Thomas Backhouse, well educated and independently wealthy, devoted his life to the observation and cataloguing of astronomical and meteorological phenomena. His publications (*Monthly Notices of the Royal Astronomical Society*; *Publications of the West Hendon House Observatory*) include a wide variety of topics ranging from the green flash, aurorae, and the zodiacal light to variable stars and novae, meteors and comets, and the structure of the Universe. Backhouse was one of the earliest observers to call attention to the "… Zodiacal Light opposite the Sun" now commonly known as the gegenschein. A similar achievement was his observation of the nebulosity surrounding Merope in the Pleiades, later confirmed by **Isaac Roberts** in one of his dramatic early photographs of nebulae. Backhouse's *Catalogue of 9,842 Stars Visible to the Naked Eye* (1911) formed the basis for several atlases published for the benefit of amateur observers, but he was perhaps best recognized for his valuable contributions to variable star and meteor astronomy.

Thomas R. Williams

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Backlund, Jöns Oskar

Born **Wermland, Sweden, 28 April 1846**
Died **Pulkovo, Russia, 29 August 1916**

Jöns Backlund is best known for his lifelong research on the motion and brightness of comet 2P/Encke. A mathematician and theoretical astronomer, Backlund earned his doctorate degree in astronomy from the University of Uppsala, Sweden, in 1875. He was hired as assistant director of the Russian Royal Observatory at Pulkovo in 1879 by **Otto Wilhelm Struve**. In 1883, Backlund was elected to the Imperial Russian Academy of Sciences of Petrograd, which allowed him to move to Saint Petersburg. Backlund was called upon by the Russian Academy to become the director of Pulkovo Observatory in 1895, following the resignation of **Fedor Bredikhin**. Backlund served in this capacity for 21 years, during which time he successfully improved the work of the observatory by employing large numbers of staff.

Backlund devoted himself to what became the passion of his lifetime, computing the orbit of the comet named for **Johann Encke**, who had devoted much of his own career to computing its puzzling orbit. Encke had proposed that there was a resisting medium near the Sun, which affected the comet's orbit. Following Encke's death, this problem was taken up by **Friedrich von Asten** until his death in 1878. Subsequently, Backlund devoted his major research efforts for the rest of his life to computing the orbit of this comet. Because of the contradictory implications of earlier observations, Backlund decided that it was necessary to recalculate the gravitational perturbations of the planets from Mercury to Saturn on Comet Encke's orbit.

Backlund participated in several international scientific projects and conferences. He also published a large volume of papers summarizing his observations related to the motion of Encke's comet. Backlund won worldwide renown for his accurate and thorough investigations; he was honored by Cambridge University with a "Doctor in Science" in 1904. He was also awarded the Royal Astronomical Society Gold Medal in 1909. In 1914, he was presented the Bruce Gold Medal of the Astronomical Society of the Pacific for his work on Encke's comet, as well as for his other notable scientific achievements and contributions to theoretical astronomy. Backlund has a lunar crater named for him, along with a minor planet (856) Backlunda.

Raghini S. Suresh

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Bacon, Francis

Born **London, England, 22 January 1561**
Died **London, England, 9 April 1626**

Francis Bacon is probably best known for his work on scientific method, but he also developed the last significant geocentric cosmology, around 1611–1612.

Bacon was the youngest son of Sir Nicholas Bacon, Lord Keeper of the Great Seal, and Ann Cooke. Educated at Trinity College, Cambridge (1573–1575), he studied law at Gray's Inn intermittently from 1576, and was admitted to the bar in 1582. Subsequently he was a Member of Parliament, Solicitor General, Attorney General, Lord Keeper of the Great Seal, and Lord Chancellor.

In 1611/1612, Bacon developed a geocentric cosmology, the last significant such cosmology outside Jesuit circles. This cosmology had a number of distinctive features. First, it was homocentric, the Earth lying at the center of a system of spheres, all the planets and other celestial bodies having regular orbits around the Earth. Such a system was probably the first ever devised, and was perceived to suffer from notable difficulties, such as the fact that the nearer planets vary in brightness in a continuous and systematic way. **Ptolemy** had tried to resolve the complexities of the astronomical data by abandoning concentric spheres and introducing epicycles and movable eccentrics, but his system appeared to many to be merely a device for saving the appearances and lacked a natural–philosophical rationale. From the 12th century onwards there were attempts, most notably in the work of **al-Bitruji**, to revive a homocentric system. Bacon was very much in this tradition, but he showed even less interest in the astronomical detail than his predecessors, seeing disputes over heliocentrism as being purely mathematical, and having no interest whatsoever in accounting for retrograde motions.

Secondly, the system Bacon devised had fluid spheres, as opposed to solid crystalline spheres or to a void, and the ether filling the celestial regions thinned out as one moved away from the Earth, which facilitated the daily rotation of the heavens around the Earth. Bacon had a complex matter theory underlying his cosmology, but the Earth was at the center of the cosmos because it is a cool, massive body. His one concession to saving the phenomena – to account for various observed phenomena such as retrograde motions and systematic variations in brightness – was to assume that the outer planets followed tight "spirals" (actually helices wound around spheres rather than strict spirals). These approximated to circles, whereas the inner ones followed more open "spirals." Evidence of the motion of the heavens around the Earth was evident in the winds and tides, Bacon believed, although here he did introduce a number of devices to save the phenomena.

Bacon's cosmological writings were not published in his lifetime, and the heliocentric theory (in one version or another) was sufficiently well established by the middle of the century for them to appear hopelessly behind the times. They represent the last attempt to pursue cosmology purely in terms of matter theory, without regard to detailed astronomical observations and mathematical calculation.

Stephen Gaukroger

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Bacon, Roger

Born **England, *circa* 1214–1220**
Died **England, *circa* 1292**

Roger Bacon is known for promoting the mathematical sciences, and encouraging the use of observation and experience in scientific study.

Very little of Bacon's life can be dated securely. His date of birth is calculated backwards from a comment in his *Opus tertium*, written about 1267, in which he states that he had learned his alphabet 40 years ago, and spent all but two of those forty years *in studio*. If *in studio* refers to Bacon's time at universities, this places his entrance into university life at about 1227; typically, students entered a university at age 13, thus placing his birth in about 1214. On the other hand, if he truly learned his alphabet in 1227, this would place his birth in about 1220, as his elementary education would probably have begun around age seven. No authoritative records of Bacon's birthplace have survived, though both Ilchester in Somerset and Bisley in Gloucestershire have been suggested. Because he was able to spend large sums of money on books and instruments for his scholarly work, he was probably from a relatively well-to-do family.

Bacon seems to have received his education at both the universities of Oxford and Paris, and received his MA around 1240 from one of these universities. In the early 1240s he was in Paris, lecturing on **Aristotle** in the faculty of arts at the university; he left the faculty around 1247. For the next 10 years Bacon spent time at both Oxford and Paris, perhaps earning a Master's degree in theology.

In 1256 or 1257, Bacon entered the Franciscan Order. The next 10 years were a somewhat difficult time for him, as he later complained that his superiors hampered his efforts to continue his studies. In the early 1260s, he contacted Cardinal Guy le Gros de Foulques, asking for patronage. The cardinal responded positively, asking to see the writings Bacon had produced, misunderstanding that Bacon in fact wished support to produce writings. In 1265, the cardinal became Pope Clement IV, and Bacon received an order from him in 1266 to begin producing the works they had previously discussed. This put Bacon in a difficult situation, as rules of the Order prevented friars from publishing books without the approval of their superiors, approval he would have been hard-pressed to receive, as many of his ideas about philosophy and the arts were suspect. Nonetheless, Bacon produced a large number of works after 1266, including his *Opus maius*, *Opus minus*, *Opus tertium*, *De multiplicatione specierum*, *De speculis comburentibus*, *Communia mathematica*, *Communia naturalium*, *Compendium studii philosophie*, and *Compendium studii theologie*, all of which include portions on astronomy and natural philosophy. He died around 1292, probably shortly after completing the final work in the preceding list.

Bacon has been pictured both as a magician and as a proto-modern experimental scientist. Neither of these characterizations accurately portrays the medieval context in which he operated. Bacon's foremost concern was to promote an educational program that would benefit Christendom. Among the more revolutionary aspects of this program were an increased role for the mathematical sciences, which included astronomy, and the establishment of a *scientia experimentalis*, often translated as "experimental science," but perhaps better translated as "experiential science."

Bacon's arguments promoting the mathematical sciences were largely practical ones: that a greater understanding of the mathematical sciences would ultimately benefit theology; aid in directing Christendom, for example, by predicting famines and wars or creating marvelous new inventions; and assist in the conversion of infidels. Astronomy, one of those mathematical sciences, brought with it a complication, for medieval astronomy was bound up inextricably with notions of astrological influence, and had thus been the subject of theological polemic for a number of centuries. Aristotelian science, which was becoming better known to Latin readers through the translation efforts of the 12th and the 13th centuries, assumed that the eternal, unchanging celestial realm exerted an influence upon the changeable terrestrial realm. Bacon wished to promote the practical benefits that astrological prediction was assumed to hold under this principle of celestial influence.

A significant issue for Bacon was to determine the limits of astronomy and the astrological predictions it could make, and in particular to differentiate between proper astronomy and "magic." Bacon proposed that, through the refinement of astronomical knowledge, the astronomer could produce accurate predictions of the future, though within certain limitations, such as those imposed by an incomplete knowledge of the positions and motions of the heavenly bodies. Material things are more strongly influenced by the heavens; for example, Bacon reinforced the medical knowledge of the day by stating that astrological influences upon the body and its parts are a necessary consideration for the physician. The human soul, on the other hand, while it can be influenced, cannot be compelled by celestial influences. Bacon repeated the Ptolemaic dictum that astrological predictions by necessity remained fallible, and were more accurate when concerned with universals rather than particulars.

Bacon also argued that the study of astronomy would aid in the correction of the calendar. It had been recognized that the solstices did not fall on the proper days, and that the length of the year in the Julian calendar was not correctly calculated. Incorrect dates could lead to religious festivals, especially Easter, being celebrated on the wrong day. Bacon advocated the removal of one day every 125 years. (Essentially the same as the later Gregorian reform, Bacon was not the first to propose this.)

Bacon argued that astronomy, along with the other mathematical sciences, would benefit from the increasing application of a *scientia experimentalis*. Experience, as an aid to (but not a replacement for) reason, could establish the certainty of deductive reasoning, add new knowledge to the existing sciences, and reveal new sciences that might lead to marvelous inventions. Bacon's ideas about the role of experience surely had some effect in increasing the role of observation and experimentation in natural philosophy.

Bacon himself was no astronomer, though his works do demonstrate familiarity with the basics of the astronomy that was being taught in the universities of that period, such as the motions of the planets and the nature of the celestial bodies. His works range over a much wider variety of issues than just astronomy. He promoted, for example, the study of *perspectiva*, a science related to optics, as well as the science of alchemy. He composed Greek and Hebrew grammars, and wrote on a number of other philosophical and theological issues. But an examination of Bacon's astronomical concerns demonstrates the different methods and goals that medievals used to investigate a scientific field, as well as Bacon's place within the history of astronomy.

Matthew F. Dowd

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Bailey, Solon Irving

Born **Lisbon, New Hampshire, USA, 29 December 1854**
Died **Norwell, Massachusetts, USA, 5 June 1931**

Solon Bailey, a prominent American astronomer in the late 19th and early 20th centuries, was known primarily for his discovery and study of variable stars in globular clusters, now known as RR Lyrae stars, and for his extensive long-exposure photographic surveys of southern skies and photometric catalog of southern stars.

After receiving an M.A. from Boston University, in 1884, and teaching at Tilton Academy for a short period, Bailey entered graduate studies at the Harvard College Observatory, where he earned a second M.A. in 1888.

In 1889, **Edward Pickering**, the Harvard College Observatory director, sent Bailey to survey the Andes Mountains for possible sites for a southern extension of the Harvard College Observatory. After several arduous years of travel up and down the Andes chain, Bailey recommended a site near Arequipa, Peru, as the best of several possible sites for an astronomical observatory. Pickering accepted that recommendation, and sent his brother, **William Pickering**, along with **Andrew Douglass** and a small staff of other Harvard personnel, to Arequipa. W. H. Pickering directed the construction of the observatory and establishment of the observing program. However, after several years of poor communication between Cambridge and Arequipa, during which W. H. Pickering spent much more of the available money than anticipated for construction, and failed to establish the type of stellar observing program desired, in 1893 E. C. Pickering recalled his brother to Cambridge, and asked Bailey to again take charge of Harvard's southern station. Bailey and his family returned to Arequipa, where they remained until he was replaced by Frank Hinkley in 1909. The Baileys returned to Peru a total of five times.

One of Bailey's primary accomplishments after returning to Arequipa was the extension of the Harvard Photometry to the South Celestial Pole. Using a meridian photometer brought from Cambridge, Bailey cataloged the brightness of 7,922 stars not visible from Massachusetts. This southern extension to provide full sky coverage contributed substantially to the later acceptance of the Harvard system as an international standard.

Among the other projects Bailey initiated as part of the observing program of the Arequipa station was photography of nebulae and globular clusters. That project included taking objective prism plates for the Henry Draper Memorial project with the Bruce 24-in. doublet photographic telescope. Bailey's assistants carefully examined the plates they took to ensure adequate quality of the recorded spectra, and were thus the first to have the opportunity for discoveries of new objects photographed on each plate. After resolving a minor dispute over roles and priorities with **Williamina Fleming**, Harvard's first famous woman astronomer, Bailey and his assistants discovered a number of new variable stars based on the presence of certain characteristic hydrogen emission lines in the stellar spectra. Between 1895 and 1898 he and his assistants found over 500 globular cluster variables, most of which were to be later to be classified as the RR Lyrae stars. Bailey's determinations of the periods of these variables, all within the range of 0.5 to 1.5 days, proved extremely accurate. The long exposure plates collected during this survey constituted a rich resource for later studies of clusters, galaxies, and nebulae in the southern skies.

The short focal length of the Bruce telescope limited its ability to resolve stars in the crowded regions of globular clusters. Bailey realized that a large telescope and very sensitive plates were critical for his work. At that time there was only one observatory in the world with the necessary equipment – the Lick Observatory in California. E. C. Pickering requested that Lick make plates of M3 with the 36-in. Crossley reflector. The Lick plates would be an important part of Bailey's 1913 presentations of the variable stars in Messier 3. Bailey's studies of variable stars in clusters were extended to M5, M15, and Omega Centauri.

From his site survey work, Bailey recognized the value of regular meteorological observations, and established a series of meteorological stations along the Andes. The stations included what was then the highest meteorological station in the world atop a nearby Andean volcano, 19,000-ft "El Misti." Other meteorological stations were placed along the coast at sea level as well as on various peaks and high plateaus in the Andes. Over the next 41 years (from 1889 to 1930) Bailey published regular *Peruvian Meteorology* reports for this South American network.

After returning from Peru, Bailey was active in the astronomical community in the Boston area. In 1912, after the retirement of professor Arthur Searle, Bailey was appointed Phillips Professor of Astronomy. In 1918, he served as one of the incorporators of the American Association of Variable Star Observers [AAVSO]. After Edward Pickering's death in 1919, Bailey became acting director of the Harvard College Observatory. However, it was the young **Harlow Shapley** who would eventually become director of the observatory, and not Bailey. Perhaps it was Bailey's age (64), and Shapley's youthful exuberance, which prevailed in that decision. To a great degree, Shapley's success in the area of globular clusters and variables was due to his collaboration and communications with Bailey.

Solon Bailey's legacy remains his observations, which are considered a foundation for those of the likes of Shapley who would follow him. He was elected president of the International Astronomical Union's Commission on Variable Stars in 1922. He was elected a member of the National Academy of Sciences in 1923. The University of San Augustine, Peru, conferred an honorary Ph.D. degree on Bailey in that same year.

Bailey's wife, Ruth Poulter Bailey, and young son Irving Widmer accompanied him on many trips to Peru. Irving spent most of his boyhood in Peru, accompanying his father on trips in the Andes, trips which ranged from jungle to barren mountain slopes. Bailey and his family also were to endure the death throes of the Peruvian Aristocratic Republic's "Revolution of 1895." This revolution culminated in the Aristocratic Republic, during which Peru experienced relative political harmony and rapid economic growth as well as social and political change.

Robert D. McGown

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Baillaud, Edouard-Benjamin

Born **Chalon-sur-Saône, Saône et Loire, France, 14 February 1848**
Died **Toulouse, Haute-Garonne, France, 8 July 1934**

French astronomer Benjamin Baillaud is best remembered today for his seminal roles in the founding of the *Carte du Ciel* project (the first photographic atlas of the sky) in the late 19th century and in the establishment of the International Astronomical Union just after World War I. He was, in many ways, the French counterpart of **George Hale**.

Baillaud, whose father was an employee at the city hall of Chalon, came from a large and modest Burgundian family of seven children and received scholarships to the Lycée of Lyon, where he studied special mathematics. Passing through the École Normale Supérieure (1866–1869), he taught in several French lycées until 1878, even as he became an assistant to **Urbain Le Verrier** (1872) at the Paris Observatory and a specialist in mathematical astronomy (1874). After obtaining his doctorate in science (1876), Baillaud lectured at the Sorbonne on dynamical astronomy (1877) as a substitute for Le Verrier who was ill.

In 1878, Baillaud was appointed director of Toulouse Observatory and the year after as dean – he was the youngest in France – of the Faculty of Science of Toulouse University. He gave a great impetus to both institutions, attracting collaborators and teachers of talent. At the university, Baillaud developed considerably the Faculty of Science, with the construction of new buildings, an increase in the number of chairs from nine to 20, and the appointment in Toulouse of scientists, since famous, such as **Emile Picard**, **Marie Henri Andoyer**, Aimé Cotton, and Paul Sabatier. In 1886, the journal *Annales de la Faculté des Sciences de Toulouse*, for mathematical and physical sciences, was created following his proposal.

Baillaud remained director of the Observatory of Toulouse for 30 years, and converted a small establishment into an important one. The domain surrounding it was enlarged, new instruments were acquired, and laboratories relating to meteorology, magnetism, mechanics, electricity, measures, and calculations were reorganized or developed. The work done under his direction includes observations of sunspots from 1879 onwards and equatorial observations of satellites, double stars, comets, and asteroids. On Baillaud's initiative, the Toulouse Observatory was involved, in 1887, in the plan for the photographic *Carte du Ciel* and its catalog.

Baillaud himself was interested in planetary theory. He wrote several memoirs on the development of the perturbing function, investigated the orbits of the five interior satellites of Saturn, and discussed the numerical calculation of definite integrals by methods of quadrature. In this regard his part in the founding of an astronomical station (1903) at the Pic du Midi (2865 m) elevation, in the French Pyrenees, was very important.

The small meteorological station existing at Pic du Midi was turned into a major astronomical observatory. Pic du Midi went into regular use in 1908, the very year that Baillaud was appointed director of the Paris Observatory. The next year he set up a small telescope (1909) so that planetology could be developed at Pic du Midi.

After Toulouse Observatory, Paris Observatory for twenty years took advantage of Baillaud's expertise in organizing and leadership. Soon after his arrival, he convened at Paris the Standing Committee for the *Carte du Ciel*, to regulate celestial photography, to produce the astrographic catalog, and to discuss the results obtained from the observations of Eros in 1900/1901. He was elected as its president (1909).

In 1911, again, Baillaud held an international meeting on astronomical ephemerides, where the directors of the principal astronomical almanacs agreed to the standardization of working methods, and a suitable division of work among them, to establish a fundamental star catalog.

The Paris Observatory did not actually permit astrophysical research. Instead, Baillaud improved the meridian service and took advantage of the advancement of wireless telegraphy to use it for a more accurate determination of longitudes by transmitting time information. General Ferrié was in charge of the wireless station at the Eiffel Tower, and in 1910, for the first time, signals were emitted from the Eiffel Tower according to a clock at the Paris Observatory. After this the two men conceived a vast project for continuation of the universal adoption of Greenwich Meridian Time.

Two international conferences (1912 and 1913) were convened at Paris to institute a Commission internationale de l'heure (International Hour Council) and a Bureau International de l'Heure at the Paris Observatory. Baillaud was chosen as the director. During World War I (1914–1918) he never failed to maintain the transmission of time from the Eiffel Tower, although the monument was particularly threatened by gunfire.

Immediately after the armistice, scientists began reorganizing, and in July 1919, the Conseil International des Recherches (International Research Council) was instituted at Brussels. Under its wing the Unions Internationales (International Unions) were formed. Baillaud was one of the most active creators of the International Unions (which owe to him their French names). Among them was the Union Astronomique Internationale (International Astronomical Union [IAU]), combining the *Carte du Ciel*, the Solar Union, and the Bureau International de l'Heure. Baillaud was elected the first IAU president (1919–1922).

Baillaud was a member of the Académie des sciences (1908), a member of the Bureau des longitudes (1908), an associate member of the Royal Astronomical Society (1908), a corresponding member of the Imperial Academy of Sciences of Saint Petersberg (1913), and an associate member of the Accademia dei Lincei (1918). He was awarded the Bruce Medal (1923*)* of the Astronomical Society of the Pacific.

Baillaud continued the directorship of the Paris Observatory until 1926, his main interest being the Astrographic Chart and the Wireless Time Service. Then he retired in Toulouse.

Baillaud was known as a remarkable professor and was admired for his modesty, integrity, cordiality, and administrative proficiency. He had eight children; two among them were astronomers: Jules and René Baillaud. (René Baillaud was director of Besançon Observatory: 1930–1957.)

Raymonde Barthalot

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Bailly, Jean-Sylvain

Born **Paris, France, September 1736**
Died **Paris, France, 12 November 1793**

Jean-Sylvain Bailly, a French astronomer and politician, was largely known for his contributions to astronomy and his tragic political career. After studying with **Nicolas de La Caille** and **Alexis Clairaut**, Bailly computed orbits of various comets and, using Clairaut's theory, made the first effort to improve the tables of the satellites of Jupiter. Such tables were widely used for navigation and surveying purposes at the time. By applying theoretical rather than empirical methods, Bailly attempted to predict the perturbations in their orbits more accurately and thus make the tables more accurate. In 1771, Bailly published his most noteworthy scientific work, a study of the inequalities of light observed in the immersion and emersion of Jupiter's satellites during their eclipse in the Jovian shadow. Using a new observational technique, Bailly related those anomalies to the characteristic amount of light reflected by each satellite and its diameter, and suggested further improvements in the observational methods involved.

As a result of his various works, Bailly was elected to the Académie des sciences in January 1763, elected to the Académie française in 1783, and appointed by the king to the Académie des inscriptions et Belles-Lettres. Only one other individual had ever been a member of all three academies prior to Bailly.

Commission appointments and other services on behalf of the Académie des sciences led Bailly into nonastronomical investigations, the result of which was a greater public appreciation of his skills. He was named spokesman for the Paris delegation to the Estates General, and on 20 June 1789, Bailly led the Third Estate in taking the Tennis Court Oath that led to the creation of the National Assembly. Bailly was then elected first president of the assembly. On 15 July 1789, Bailly was unanimously proclaimed the first mayor of Paris, a position to which he was reelected in 1790. After the massacre on the Champ de Mars, Bailly fell from popularity and retired, but was still charged with conspiracy and guillotined.

Ednilson Oliveira

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Baily, Francis

Born **Newbury, Berkshire, England, 28 April 1774**
Died **London, England, 30 August 1844**

Although he is better known for his recording of the solar eclipse phenomenon now known as Baily's beads, Francis Baily's most important contributions to astronomy include his recomputation and republication of important star catalogs, and his determination of the ellipticity and density of the Earth.

Before turning his wealth to his interest in astronomy, Baily had many adventures. The third son of banker Richard Baily, he had been apprenticed to a London mercantile firm at the age of 14. But by the age of 21, when he had completed his apprenticeship, Baily had instead decided on a career as an explorer. In October 1795, Baily sailed to the United States, where his youthful energy carried him through 2 years of exploration along the Ohio and Mississippi rivers from Pittsburgh, Pennsylvania, to New Orleans, Louisiana. He returned to New York City overland through the rugged back-woods areas. A romantic attachment nearly induced Baily to remain in the United States, but his ambitions for exploration were apparently strong. Returning home in March 1798, he failed to find financial backing for exploration in Africa, and instead became a stockbroker the following year. During his successful business career, Baily acquired a substantial reputation for the accuracy of his actuarial computations, publishing a number of successful monographs on the subject. He retired with a large fortune in 1825 at the age of 54 and pursued his interest in astronomy, a field in which he was very active until his death.

Before his retirement from business, Baily's interest in history and the tabulation of data drew him to publish several historical works, including a paper on the solar eclipse that **Thales** was said to have predicted. Although that paper was later corrected by **George Airy** based on improved lunar tables, Baily apparently enjoyed both the historical and the mathematical aspects of calculating the date on which that ancient eclipse had occurred. The project launched his career in astronomy. At the time of his retirement, Baily already had been one of the leading founders of the Astronomical Society of London, later chartered as the Royal Astronomical Society [RAS]. He served as the RAS president for 8 years.

Baily's next astronomical achievement involved methods of determining latitudes and local times. He aimed to improve the notoriously erroneous *British Nautical Almanac* by recalculating the positions of 2,881 stars for the epoch 1 January 1830. His revised catalog was published by the Astronomical Society in 1826. For his efforts on this catalog, Baily was awarded the RAS Gold Medal in 1827. It was on the basis of Baily's protests in 1819 and 1822, as well as his revised catalog of stars, that the *Nautical Almanac* reforms of 1827 were undertaken.

On the basis of that experience, Baily made an astronomical career of revising and republishing a number of important star catalogs. In 1835, he published a revised edition of **John Flamsteed**'s *Historia Coelestis* of 1712, including in the accompanying text a vindication of Flamsteed in the latter's acrimonious dispute with **Isaac Newton** and **Edmond Halley**. Baily displayed considerable understanding in concluding that "even amongst men of the most powerful minds, science is not protection against the common infirmities of human nature: and that however much we may admire their intellectual attainments, we must ever regret their exhibition of any human frailty."

Baily secured the sponsorship of the British Association for the Advancement of Science for his pursuit of correcting and republishing tables of star positions, and for the most part carried out these revisions himself. Baily's revision of **Joseph de Lalande**'s *Histoire céleste française* of 1801, listing 47,390 objects including nebulae, was published in 1847. Other catalogs revised and republished by Baily included the historic catalogs of **Ptolemy**, **Ulugh Beg**, **Tycho Brahe**, **Johannes Hevelius**, and **Tobias Mayer**, and the important catalogs of Southern Hemisphere stars of Halley and **Nicolas de La Caille**, with the help of **Thomas Henderson**.

Baily also worked on a number of problems related to the size and density of the Earth. He completed and discussed the pendulum experiments of H. Foster, applying a correction that had previously been overlooked, and deduced from them an ellipticity of the Earth of 1/289.5. Baily also repeated and extended the work of **Henry Cavendish** aimed at determining the mean density of the Earth, an effort for which the RAS awarded him a second Gold Medal in 1843. Baily is one of only four persons to be so recognized twice, the others being **John Herschel**, **William Huggins**, and **David Gill**.

Today Baily is mainly known for the so called Baily's beads phenomenon, transient light irregularities that may appear on the lunar limb during solar eclipses. He first observed the phenomenon during an annular eclipse on 15 May 1836 at Inch Bonney, Roxburghshire, England. Baily gave a vivid description of the phenomenon as like a string of bright beads, and gave the correct explanation: Sunlight is blocked by lunar mountains, but passes through the intervening valleys. Although others had reported seeing this phenomenon at earlier eclipses, Baily's description was so graphic that his name has been associated with it since that time. Since then, eclipse chasers from all countries have hoped to see once in their lives this rare and spectacular phenomenon.

Baily was elected a member of the Royal Society in 1821. He served for a number of years as a vice president, and also as a treasurer of that organization.

Jean-Pierre Luminet

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Bainbridge, John

Born **Ashby-de-la-Zouch, Leicestershire, England, 1582**
Died **Oxford, England, 3 November 1643**

As one of the first astronomers to observe a comet telescopically and compute its parallax, and as the first Savilian Professor of Astronomy at Oxford University, John Bainbridge established a high standard for both research and pedagogy for his successors in academic astronomy. Bainbridge, the son of Robert and Anne (*née* Everard) Bainbridge, attended grammar school in Ashby, England, and later entered Cambridge University where he received his B.A. in 1603, M.A. in 1607, and M.D. in 1614. Bainbridge returned to Ashby in 1614 where he established his medical practice, and started a grammar school at which he taught for 4 years. In what little leisure time was available to him, he occupied himself with the study of mathematics and astronomy.

On the advice of some friends, Bainbridge moved to London in early 1618, where he soon became a member of the "Gresham Circle," a group of Puritan scholars and college professors that included Robert Hues, Nathaniel Carpenter, and Henry Briggs, the first professor of geometry at Gresham College. During his brief London stay, Bainbridge lectured on astronomy and medicine at Gresham College and was made a licentiate of the College of Physicians of London on 6 November 1618.

In 1619 Bainbridge published his major contribution to astronomy, a small tract entitled *An Astronomicall Description of the late Comet from the 18. of Novemb. 1618. to the 16. of December following*. In the tract, Bainbridge detailed his personal observations of the historic comet, including drawings of its relative position and appearance in the sky, dating from 18 November to 16 December 1618 (Julian calendar, new calendar dates – 28 November to 26 December 1618). In a fascinating series of observations during the 2nd week of December, Bainbridge became one of the first astronomers to observe a comet telescopically. He followed the comet with respect to two nearby stars, and by comparing the relative positions of the comet and the stars, both near the horizon and at the zenith, he estimated that the comet's distance from the Earth had to be more than ten times the Earth–Moon distance. Bainbridge's telescopic estimation of the parallax of comet C/1618 W1, his criticism of the Ptolemaic system, and his preference for a heliocentric worldview, all combine to make *An Astronomicall Description* a remarkable publication for its time.

While the observations as set down in the book make plain Bainbridge's conviction that the comet had natural causes and a natural movement, and thus insufficient cause to deem it a miracle, Bainbridge does retain the miraculous as a theoretical possibility. Yet Bainbridge devotes the majority of *An Astronomicall Description* to presenting newly gathered astronomical information and its analysis.

More curious, however, is Bainbridge's use of astrological conventions in interpreting the comet. Bainbridge wrote how he deplored the illusory principles of "vulgar Astrologie," yet could not refrain from proffering his own prognostications. What is striking in this is that in an age when astrology was an important topic for most men of learning, Bainbridge's closest associates strongly opposed it. Perhaps Bainbridge did at that point believe in the colloquial notion of comets being omens, but it is known that in the year before he died, Bainbridge wrote *Antiprognosticon*, in which "is briefly detected the vanity of astrological predictions grounded upon the idle conceits of celestial houses and triplicities." As the title of this unpublished treatise suggests, Bainbridge argued for astronomical events as being matters that agree with stated natural laws. Thus, *Antiprognosticon* constituted his rejection of all astrological tenets.

At some point in late 1618 or early 1619, Henry Briggs introduced Bainbridge to Sir **Henry Savile** at Gresham College, probably to exchange observational information regarding the comet and various eclipses. Savile was in the process of establishing two professorships for the teaching of mathematics and astronomy at the University of Oxford. Savile (an ardent Puritan) appointed Bainbridge to be the first Savilian Professor of Astronomy at Oxford University in 1619 partly on the basis of Bainbridge's astronomical work with the comet, his enthusiasm for the subject, and perhaps also the growing anti-Puritan climate of London.

Savile laid down very precise conditions on how astronomy was to be taught. The Savilian professor was required to teach the classical texts, such as **Ptolemy**'s *Almagest*, but new theories were to be presented as well, explicitly the *De Revolutionibus* of **Nicolaus Copernicus**. Other requirements included the teaching of spherics, optics, geography, elements of navigation, and calculation with sexagesimal numbers, and to conduct independent research. He likewise had to make his own instruments and carry out his own observations with them, which, like the lecture notes, were to be deposited in the Bodleian Library. These conditions were given to ensure that astronomy would develop and not be simply a subject fixed by the classical writers. One final condition prohibited the teaching of astrology in any guise, which makes Bainbridge's appointment intriguing in light of his recently published *An Astronomicall Description*.

Bainbridge, in accordance with the statutes of his professorship, also conducted research in ancient astronomy and chronology. In 1620, he published a combined Latin translation of the ancient Greek astronomical works **Proclus**'s *On Spheres*, Ptolemy's *On the Hypotheses of Planets*, and *Canon regnorum*. Because of his studies in chronology and ancient astronomy, and very probably his mutual friendship with Henry Briggs, Bainbridge joined a vibrant milieu of Oxonians working with James Ussher. Beginning in 1622, Bainbridge engaged in correspondence with Ussher and set to work on a method for calculating eclipses at his request. Such was their relationship that Bainbridge bequeathed his lecture notes, unpublished manuscripts, and personal correspondence to Ussher.

Bainbridge also wrote what many consider the most original of all 17th-century works on ancient chronology, the *Canicularia*, which dealt with the risings and calendrical import of Sirius in the ancient world. Considered to be Bainbridge's last publication, this work displays "a formidable knowledge of ancient literature as well as of astronomy and chronology." Begun in 1626, it was published posthumously in 1648 under the care of **John Greaves**, Bainbridge's former pupil and immediate successor as Savilian Professor of Astronomy.

Bainbridge's lasting legacy in chronology is often associated with his role in calendar reformation, principally his correction of Joseph Scaliger. In addition to the *Canicularia*, his compositions on chronology are found in several works of the period, including George Hakewill's *An Apologie or Declaration of the Power and Providence of God in the Government of the World* (1627), Ralph Winterton's *Hippocratis magni aphorismi* (1633), and the *Theatrum Botanicum* of John Parkinson (1635).

Oxford University witnessed a qualitative leap forward in the improvement of scientific teaching and learning during Bainbridge's 24-year tenure as the first Savilian Professor of Astronomy. In planning and conducting research, Bainbridge proved himself to be meticulous and passionate. In the Bainbridge papers at Trinity College, Dublin, for example, there is his "Catalogue of Instruments" that includes proportional compasses (*i. e.*, sectors); the mesolabium; the armillary sphere; the solid sphere; the ordinary and universal astrolabes; the astronomer's cross-staff; the geometrical staff; quadrants; dials; the astronomer's ring; the ordinary; variation and declination compasses; various telescopes; and numerous maps. In addition, Bainbridge's observations may be found in the papers of his contemporaries, both in England and abroad, for example **Ismaël Boulliau** and **Pierre Gassendi**. Reciprocally, Bainbridge often sought out their advice on astronomical matters.

Bainbridge's notebooks indicate a deep interest in all types of astronomical phenomena, and his observations of various eclipses, the Moon, and the 1631 transit of Venus illustrate meticulous attention to detail in recording as well as his drive to gather the requisite observations. Despite the unkind fate that plagued Roger Fry's 1631 expedition to South America, Bainbridge orchestrated several observations in England that provided data for the eventual explication of the longitude problem. Bainbridge also determined the latitude of Oxford in 1623. The Bainbridge papers reflect, as Mordechai Feingold suggests, "an indefatigable astronomer familiar with the most recent observations and speculations, who both applied such contemporary accounts to his own research and integrated them into his teaching."

Patrick A. Catt

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Baize, Paul-Achille-Ariel

Born **Paris, France, 11 March 1901**
Died **Laval, Mayenne, France, 6 October 1995**

Paul Baize pursued a distinguished career in pediatrics while developing an equally distinguished astronomical career as a specialist in binary stars. As an amateur astronomer, Baize made over 24,000 exceptionally accurate binary star measurements using the 30-cm and the 38-cm refractors of the Paris Observatory, and calculated nearly 300 orbits based on his observations. His publications included a catalog of binary star orbits (1950), a stellar mass–luminosity relationship (1957), a catalog of red dwarf binary stars (1966), and over 200 other astronomical papers. Baize was elected to membership in the International Astronomical Union in 1936. He was honored with the Amateur Achievement Award of the Astronomical Society of the Pacific in 1987, and elected an *Officier* of the Legion of Honour.

Paul Couteau

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Bājja

➔ **Ibn Bājja: Abū Bakr Muḥammad ibn Yaḥyā ibn al-Ṣā'igh al-Tujībī al-Andalusī al-Saraqusṭī**

Baker, James Gilbert

Born **Louisville, Kentucky, USA, 11 November 1914**
Died **Bedford, New Hampshire, USA, 30 June 2005**

Although trained chiefly in mathematics and astrophysics, James Baker also possessed a deep and abiding interest in optical design and fabrication, his particular forte being the design of telescopes and cameras of unprecedented fast photographic speed, wide field of view, and overall high image quality including the Baker–Nunn camera. Baker had a keen appreciation for what instrumentation could produce in terms of data, and also a fundamental understanding of how instruments worked on both a practical and theoretical basis. An experienced observer from his student days, Baker was able to define problems with existing astronomical instrumentation and combine aspects of theory, observation, design, and fabrication to produce new, more perfect, and more useful astronomical and photographic instruments. Even while creating new optical designs not directly associated with astronomy, Baker always kept in mind possible astronomical applications.

Baker was the son of Jesse Blanton and Hattie May (*née* Stallard) Baker. His interest in astronomical optics began as a high-school student when he produced his first optical component, a simple 3-in. lens that he used to view the Moon. While studying as much astronomy as possible, Baker graduated with a B.S. in mathematics from the University of Louisville in 1935. He then entered Harvard University as a graduate student in astronomy. On the basis of his success as an undergraduate, Baker was awarded a Junior Fellowship to attend the first Harvard Summer School.

Baker's first year in Cambridge, Massachusetts, proved important for his eventual career. At the Harvard University Tercentenary Celebration, in the fall of 1936, Baker met Richard Scott Perkin who, at that time, was looking for opportunities for self-employment. At that same meeting, Perkin also met Charles Elmer, and it was in that chance meeting that the two agreed to form the Perkin–Elmer Corporation. A close friendship between Baker and Perkin evolved over subsequent years. In addition to many consulting assignments for Baker on Perkin–Elmer projects, Perkin attempted several times to recruit Baker as an employee, and twice invited Baker to become a director of the corporation. Preferring to stay focused on science, especially astronomy, Baker was consistent in refusing all such entreaties. The Baker and Perkin families became close friends socially; Baker eventually served as a director and a key contact for the Perkin Foundation.

Baker's primary research work as a Harvard Junior Fellow and graduate student involved spectroscopy and the physics governing gaseous nebulae. His graduate research in astrophysics was done in collaboration with **Donald Menzel** as well as **Harlow Shapley**. After passing qualifying exams in 1938, Baker's interest in optics and instrumentation as well as the astrophysics of the nebulae led him to construct a new grating spectrograph to replace an aged prism-type instrument that had been used on the 61-in. reflector at Harvard's Oak Ridge Observatory. He taught a course on mathematical optics in Harvard's mathematics department in 1941. Baker defended his doctoral thesis, *Investigations in the Theory of Optics with Astronomical Applications* and was awarded a Ph.D. in the summer of 1942.

Like other scientists at the beginning of World War II, Baker was harnessed to the war effort, working as an advisor on military optics for the United States. In 1941, Shapley brought Baker's talent as an optical designer to the attention of the Kodak Corporation and the United States Army Air Corps. In addition to his involvement in other wartime projects, Baker headed the Harvard Observatory Optical Project from its inception in the summer of 1941 to its closing in 1945. Working originally in the basement of the Harvard College Observatory, Baker and a team of as many as 25 professional and amateur optical workers produced prototypes of very high-quality large-aperture aerial camera lenses. Baker also participated in optical research work at the Air Force's Wright Field in Dayton, Ohio. After the war, Baker continued optical design work for the government, industry, and for Harvard. Significantly, the lenses designed by Baker during and after World War II were, almost without exception, designed not only for military reconnaissance, but also as potential astrographic cameras. Baker never lost sight of these possible dual applications, although military security often prevented such use until much later.

Baker was appointed associate professor at the Harvard College Observatory in 1945. He continued to work intermittently as a professor and later as an associate until his retirement. Although not primarily a teacher, Baker did conduct courses from time to time in celestial mechanics, astrophysics, and, of course, optics. Among Baker's astronomy-related Harvard projects in the 1950s were a "Super-Schmidt" meteor camera working at *f*/0.6 with a 55° field of view for **Fred Whipple**, and an improved flat-field Schmidt camera with one additional element that was the basis for the Armagh–Dunsink–Harvard 33-in. aperture camera installed at Harvard's Boyden Station at Bloemfontein, South Africa. A further Schmidt refinement with a three-element corrector plate became famous as the Baker–Nunn camera used for satellite tracking and other wide-field astrophotographic applications.

One of Baker's more publicized projects in the 1950s was the Medial refractor, also known as the Schupmann telescope, a refracting telescope system in which a series of lenses, mirrors, and prisms can be so designed and adjusted to eliminate instrumental and atmospheric chromatic aberration. Typically, it was difficulties he encountered while observing, in this case with the 36-in. refractor at the Lick Observatory, which prompted Baker's design work with the Medial telescope. Baker proposed a 29-in. Medial refractor for astrometric applications at the Sacramento Peak Observatory in 1954, but the project was never funded. In the 1960s, Baker produced a design known as the Paul–Baker telescope, a very fast (*f*/2), wide-field, three-element reflecting telescope, an example of which is the 1.8-m CCD/transit telescope now at the Steward Observatory in Arizona. In the 1980s, Baker continued work on astrographic telescopes, in particular designs that could be used over a wide spectral region.

Baker's career was primarily one of quiet but steady consulting. In addition to his work with Harvard University, the United States Air Force, and Perkin–Elmer Corporation, Baker also served as consultant at the Lick Observatory in California, Aerospace Corporation, and Polaroid Corporation. Baker was elected to both the National Academy of Sciences and the National Academy of Engineering. He was a member of the American Astronomical Society, and the Optical Society of America, serving as its president in 1960. Baker received numerous awards including the Adolph Lomb Medal (1942), the Presidential Medal of Merit (1947), the Alan Gordon Award of the Society of Photooptical Instrumentation Engineers (1976), and the Fraunhofer Award of the Optical Society of America (1991).

In 1938, Baker married Elizabeth Katherine Breitenstein. They had four children.

Gary L. Cameron

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Baldwin, Ralph Belknap

Born **Grand Rapids, Michigan, USA, 6 June 1912**

Astronomer and businessman Ralph Baldwin received bachelor's and master's degrees in astronomy and a Ph.D. in astrophysics from the University of Michigan, where he was a student of **Heber Curtis** and **Dean McLaughlin**. After completing his doctoral dissertation in 1937, on the spectroscopic study of novae, Baldwin taught at the University of Pennsylvania (1937/1938) and Northwestern University (1938–1942) while continuing work on the development of physical models of novae and unusual binary stars. In 1942, Baldwin accepted an appointment as a senior physicist at the Johns Hopkins University's Applied Physics Laboratory, where, in a wartime group led by the geophysicist Merle Tuve, he helped to develop the radio proximity fuze.

In 1947, Baldwin returned home to Grand Rapids to help run the family business, Oliver Machinery Company. Between then and his retirement in 1984, he rose from product manager to chairman of the board of the firm, which specialized in producing woodworking machinery. Well respected in his industry, Baldwin served as president of the Wood Machinery Manufacturers of America from 1964 to 1968.

While teaching at Northwestern University, Baldwin lectured part-time at Chicago's Adler Planetarium, where he became intrigued by large photographs of the Moon exhibited there. After noticing radial markings cutting across mountains ringing Mare Imbrium, the largest lunar "sea," he concluded that this surface feature was too big to be volcanic and that the grooves were valleys "caused by material ejected radially from the point of an explosion." He determined that lines projected from the major axes of these valleys all intersected in the mare. By 1941, Baldwin had become convinced that the impact of a meteorite of "asteroidal proportions" had caused both the valleys and the mare. In a lecture that year at Yerkes Observatory, and in papers published in *Popular Astronomy* in 1942 and 1943, he argued that other circular lunar maria and virtually all lunar craters had an impact, rather than volcanic, origin.

Over the next few years, Baldwin studied not only existing literature on lunar craters, terrestrial meteorite craters, and small solar-system bodies, but using his wartime security clearance, also reviewed classified United States Army records of bomb, artillery shell, and mortar explosions; the diameters of the craters they produced; and the shapes of craters caused by explosions at, above, and below ground level. In Baldwin's book *The Face of the Moon* (1949), which presented a synthesis of these studies, he plotted the depths and diameters of the various types of craters and found that they fell along a single logarithmic curve "too startling, too positive, to be fortuitous." He thus became the first person to demonstrate a quantitative relationship among bomb explosion craters, terrestrial meteorite craters, and lunar craters. Baldwin concluded that most lunar craters had been formed by meteoroid impacts early in the Moon's history. He published an expanded version of his work as *The Measure of the Moon* (1963).

Baldwin also wrote *A Fundamental Survey of the Moon* (1965), *The Deadly Fuze: Secret Weapon of World War II* (1980), and *They Never Knew What Hit Them* (1999). He was awarded the Barringer Medal Citation of the Meteoritical Society in 2000. In 1975, 1989, and 1998 he received honorary doctorates from the University of Michigan; Grand Valley State University in Allendale, Michigan (in whose library a collection of his papers is held); and Aquinas College in Grand Rapids, where he was instrumental in the development of an observatory that bears his name.

Craig B. Waff

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Ball, Robert Stawell

Born **Dublin, Ireland, 1 July 1840**
Died **Cambridge, England, 25 November 1913**

Robert Ball was a noted lecturer and popularizer of astronomy. He was the eldest son of Irish naturalist Dr. Robert Ball. His preliminary education was completed at Abbot's Grange, Chester, whereupon he entered Trinity College, Dublin, in 1857. As an undergraduate, Ball was a gold medalist in mathematics, in the experimental and natural sciences, and was awarded a University Scholarship in 1860. He graduated in 1865.

Ball served as assistant astronomer (1865–1867) to **William Parsons**, the Earl of Rosse, at Parsonstown, Ireland, where he observed and measured faint nebulae with the 6-ft. reflector at Birr Castle. In 1867, Ball was appointed professor of applied mechanics at the newly opened Royal College of Science at Dublin and wrote a text on experimental mechanics. He married Frances Elizabeth Steele in 1868; the couple had six children.

Upon the resignation of **Franz Brünnow** in 1874, Ball became Astronomer Royal for Ireland and Andrews Professor of Astronomy at the University of Dublin. His principal work in astronomy concerned the investigation of stellar parallax; he employed visual methods with the 12-in. refractor at Dunsink Observatory. Ball's search for stars of large parallax, however, only netted two (out of some 368 stars examined). More successful were Ball's mathematical investigations into the theory of screws (a study of the dynamics of rigid bodies under particular constraints), on which he published widely between 1871 and 1904. For these efforts, Ball received the Gold Medal of the Royal Irish Academy (1879). He was likewise the recipient of two honorary degrees – an M.A. (Cambridge University) and LL.D. (University of Dublin).

Ball's popular writings included *The Story of the Heavens*, *Starland*, *In the High Heavens*, *Time and Tide*, *A Romance of the Moon*, *The Cause of an Ice Age*, *The Story of the Sun*, and *Great Astronomers*. He likewise wrote a standard textbook, *Elements of Astronomy*, along with *A Treatise on Spherical Astronomy*. Ball also did popular lecturing: on one occasion (1907), he addressed a group of convicts at Dartmoor Prison.

In 1892, Ball was appointed to the Lowndean Chair of Astronomy and Geometry at Cambridge University (succeeding **John Adams**) and director of its observatory, a post he retained until his death. Ball received the honor of knighthood in 1866. He served as president of the Royal Astronomical Society (1877–1879) and of the mathematical section of the British Association for the Advancement of Science, among other titles. Politically, Ball remained a strong Unionist.

Jordan D. Marché, II

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Balmer, Johann Jakob

Born **Lausanne, Switzerland, 1 May 1825**
Died **Basel, Switzerland, 12 March 1898**

Johann Balmer's empirical formula was shown to predict the wavelength of electromagnetic energy emitted by the quantized transition of an electron to a lower energy level in an atom.

Balmer was born to Johann Jakob Balmer and Elizabeth Rolle Balmer. He was the eldest son and attended his first school at Liestal, the capital of what was known as the half canton of Basel-Landschaft. For his secondary education, Balmer returned to Basel where he excelled at mathematics, propelling him into a university mathematics track beginning at the University of Karlsruhe, taking him through the University of Berlin, and ending with his doctorate, which he received at the University of Basel in 1849.

Balmer lived the relatively quiet life of a schoolteacher, taking up a mathematics post at a girls school in Basel, a job he held until his death. He did lecture at the University of Basel, from 1865 until 1890, in geometry. However, his publication record indicates that teaching was his primary focus, and Balmer never made any significant contribution to geometry.

Balmer married late in life, in 1868, at the age of 43. However, he and his wife Christine Pauline Rinck had six children. There is a crater on the Moon named for Balmer.

Balmer is remembered for a discovery he first published at the age of 60 (1885). In fact, he only published two papers on his discovery, the second being in 1897.

Balmer's discovery was a formula for calculating wavelengths for the spectral lines of elements. His first paper dealt only with the spectral lines of hydrogen. An initial reading of his work gives one the impression that it was Balmer's mathematical ability that gave him the insight to produce the equation, because he gives no physical explanation for it in the paper. This formula, which predicts the wavelengths of the spectral lines, is deceptively simple:

$$\frac{1}{\lambda} = R_H\left(\frac{1}{m^2} - \frac{1}{n^2}\right),$$

where R_H is the Rydberg constant for hydrogen.

In Balmer's second and last paper, he applied the same concept to other elements including helium and lithium, with results that matched observation to within a fraction of a percent. (They came to be referred to as Balmer lines or the Balmer series.) Balmer correctly predicted that many invisible spectral lines of hydrogen existed.

Balmer's formula is one of the most fundamental in all of modern astrophysics, for it allows astronomers and physicists to predict to a high degree of certainty where certain spectral lines will occur and thus provides a great deal of information on the atomic processes in astrophysical objects. But it is important to remember that despite the incredible accuracy of the prediction, the physical explanation for this phenomenon did not come until **Niels Bohr** first developed his model of the atom in 1913, fifteen years after Balmer's death. Still, Balmer's discovery stands with Bohr's as one of the most important in modern astrophysics.

Ian T. Durham

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Banachiewicz, Thaddeus Julian

Born **Warsaw, Poland, 13 February 1882**
Died **Cracow, Poland, 17 November 1954**

Thaddeus Banachiewicz combined unusual talents as a theoretician and an astronomical observer to make substantial contributions in celestial mechanics, mathematics, and geophysics. He was the youngest of the three children of Artur Banachiewicz, a landowner at Cychry (a village near Warsaw) and Zofia (*née* Rzeszotarski).

Banachiewicz studied astronomy at Warsaw University; he received a bachelor's degree in physical and mathematical sciences in 1904. His dissertation on the reduction constants of the Repsold heliometer earned a Gold Medal from the university senate. Banachiewicz continued his studies in Göttingen, Germany (1906–1907) under **Karl Schwarzschild** and later in Pulkovo, Russia (1908) under **Jöns Oskar Backlund**. On his return to Warsaw, Banachiewicz was appointed junior assistant at the University Observatory. In January 1910, following further studies in Warsaw and Moscow, Banachiewicz was engaged as an assistant at the Engelhardt Observatory near Kazan, Russia, where he stayed till 1915. Banachiewicz then moved to Dorpat (now Tartu, Estonia) in 1915 as an assistant, but in September 1917 – when he obtained the degree of *Magister Astronomiae* – he was appointed assistant professor, and later promoted to associate professor and director of the University Observatory.

In 1918, Banachiewicz returned to Poland, as a *Dozent* of geodesy at the Warsaw Polytechnic School, but was soon appointed full professor, chairman of the astronomy department, and director of the observatory at the Jagiellonian University in Cracow. Banachiewicz held these positions until his death in 1954, excluding an interruption of over 5 years during the German occupation of Poland, when Nazi forces removed the university faculty, including Banachiewicz, to the Gestapo concentration camp at Sachsenhausen near Berlin. After 3 months at Sachsenhausen, Banachiewicz was allowed to return to the observatory, renamed "Die Krakauer Sternwarte" by the Germans, where he was allowed to resume his astronomical work.

After World War II, in addition to his duties at the Jagiellonian University, Banachiewicz also accepted the duties of professor of higher geodesy and astronomy at the Cracow University of Mining and Metallurgy for 6 years (1945–1951).

The areas of Banachiewicz's scientific interest were wide, so one finds his contributions in astronomy, geodesy, geophysics, mathematics, and mechanics. His principal scientific achievements were generated through the use of the Cracovian calculus, a method that he invented.

As Witkowski and Mietelski have noted, before 1927 there was only one way of solving spherical polygons – by resolution into triangles. By using the Cracovian calculus, in 1927 Banachiewicz obtained the general relations of spherical polygonometry in two forms: one which presents the generalized formulae of Gauss–Cagnoli previously known in spherical trigonometry, while the other yields the generalized formulae of **Jean Delambre**. In 1942, Banachiewicz developed a practical but elegant Cracovian algorithm for the least-squares method. Other achievements include Banachiewicz' methods of solving the systems of linear equations (both symmetrical and unsymmetrical), and rapid computation of determinants of any degree.

Another astronomical area in which Banachiewicz' theoretical contributions were important is in the determination of a parabolic orbit. He demonstrated that the various approaches of the classical authorities (**Carl Charlier**, **Adrien Legendre**, **Armin Leuschner**, S. D. Tscherny, and **Hermann Vogel**) could, at times, give three different solutions. Banachiewicz showed that the equation of **Johann Lambert** could not be used in these singular circumstances. He then adapted **Heinrich Olbers**' method to arithmetic calculations using vectorial elements and eliminating some auxiliary angles. Textbooks today identify this thoroughly modified way of determining parabolic orbits as the Banachiewicz (Olbers) method. Banachiewicz also simplified existing procedures for the determination of elliptical orbits by introducing the chord-joining positions of the body instead of their heliocentric angles; some years earlier he had published several papers on Gauss's equation, and provided useful tables for solving it. The practical worth of Banachiewicz' orbital calculation methods may be illustrated by the fact that in 1930 an early orbit of Pluto was determined by Banachiewicz and **Charles Smiley** of Brown University, who was, at that time, studying in Cracow.

As an observational astronomer in Kazan, Banachiewicz carried out a 5-year series of heliometer observations of the Moon. Reductions of these observations by J. Mietelski (1968) by applying the Cracovian method yielded values of the principal physical libration parameters very close to modern values derived from the lunar laser ranging techniques and from perturbations of lunar orbiters.

As a student, Banachiewicz began to observe occultations of stars by the Moon in 1901, and to calculate their ephemerides (and also those of occultations by planets and their satellites). He viewed these as important phenomena for the study of the motion of the Moon. In this respect, Banachiewicz anticipated, by two decades, the work of **Ernest Brown**. In a similar way, Banachiewicz anticipated the work of **Bertil Lindblad** and others using solar eclipse phenomena for geodesy. Banachiewicz organized geodetic surveys in Poland and conducted a few Polish solar eclipse expeditions. Using the Baily's bead phenomenon, Banachiewicz' chrono-cinematographic method established the difference (Moon–Sun) in right ascension with a standard error of only ±0.04″ at the Lapland eclipse on 12 June 1927. As a result, Banachiewicz proposed, at the 1928 meeting of the Baltic Geodetic Commission in Berlin, the use of total eclipses for the purpose of connecting distant points of the Earth's surface; in this way a "lunar triangulation" could facilitate a geodetic bridging of the oceans. Banachiewicz' ideas and techniques were applied to good advantage in the 1940s and 1950s on eclipse expeditions sponsored by the National Geographic Society and various US defense agencies.

Banachiewicz founded the Polish journal *Acta Astronomica* in 1925 and many publications of the Cracow Observatory. He was the first in Poland to recognize the importance of the emerging field of radio astronomy and inaugurated the first Polish radio telescope near Cracow in 1954.

Banachiewicz was a member of the Warsaw Scientific Society, Poznań Society of Friends of Sciences, Polish Academy of Arts and Sciences, and Padova Academy. He was a foreign associate of the Royal Astronomical Society. He was also a founder of the Polish Astronomical Society in 1923 and served for 10 years as its president. In 1952, Banachiewicz was a titular member of the Polish Academy of Sciences.

From 1924 to 1926, Banachiewicz served as vice president of the Baltic Geodetic Commission. He was also a vice president and a member of the Executive Committee of the International Astronomical Union [IAU] from 1932 to 1938, and president of IAU Commission 17 (movements and figure of the Moon) from 1938 until 1952. Three universities conferred the doctor *honoris causa* upon Banachiewicz: Warsaw (1928), Poznań (1938), and Sofia (1950). The minor planet (1286) was named Banachiewicz, as was a 70-km crater on the farside of the Moon.

In 1931, Banachiewicz married Laura (or Larysa) Solohub-Dykyj, a Ukrainian poetess. There were no children from this marriage.

The personal data of Banachiewicz and documents concerning his Cracow collaborators and the Cracow University Observatory under his direction are held in the Archives of the Jagiellonian University, Cracow, Poland. The "Notaty codzienne" (a daily diary kept by Banachiewicz during the years 1932–1954, five volumes) is held privately by Jerzy Kordylewski in Cracow and may be accessed through the Jagiellonian University Observatory.

Jan Mietelski

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Banneker, Benjamin

Born **Baltimore County, Maryland, (USA), 9 November 1731**
Died **near Ellicott Mills, Maryland, (USA), 9 October 1806**

Benjamin Banneker was a mathematician, astronomer, writer, inventor, landowning farmer, and important African American intellectual. His parents were Mary Banneky, a free African American, and Robert, a freed African slave, who adopted his wife's surname upon marriage. (Over the years, the spelling of the surname became fixed as Banneker.) In 1737, Benjamin, their firstborn and only son, was named co-owner on the deed to their 100-acre farm that was located in the Patapsco River Valley of rural Baltimore County, Maryland. Benjamin had three younger sisters. He never married and had no offspring.

Banneker was taught to read and write by his maternal grandmother, Molly Welsh, a white woman who arrived from England as an indentured servant, completed her contract, and managed to assemble sufficient assets to purchase land for a farm on the Patapsco River. Banneker attended a rural Quaker school during winter months when work on his father's farm was limited, and was otherwise largely self-taught. At the age of 22, Banneker demonstrated his advanced understanding of mathematical principles when he constructed an accurate wooden striking clock using a pocket watch as a model. However, his demanding farm activities and rural surroundings ruled out any pursuit of a formal education. Banneker's three sisters married and moved from the farm; his father died in 1758, leaving Benjamin and his mother as its sole occupants. By all accounts, he was an industrious and successful farmer.

In 1772, the **Ellicott** brothers, **Andrew** and George, emigrated from Pennsylvania to Maryland and bought land along the Patapsco Falls, very near Banneker's farm, for the purpose of developing a gristmill. The community of Ellicott Mills attracted Banneker who was contracted to provide farm produce for the workmen. Soon, a friendship developed between Banneker and the young George Ellicott who introduced him to the science of astronomy. Ellicott loaned him some astronomy texts and some basic instruments that Banneker used to teach himself mathematical and astronomical principles.

With the encouragement of Ellicott, Banneker began calculating an ephemeris patterned after those published in almanacs of the period. He attempted to have his first ephemeris published in 1791, but was not successful.

Banneker's quiet rural life changed at the age of 60 years when major Andrew Ellicott, who had received a commission to survey the Federal Territory (Washington), was in need of competent assistants. Ellicott, who had reviewed Banneker's ephemeris for 1791 and was impressed by his abilities, offered him a position with the survey team that he accepted. Banneker, whose role it was to care for the delicate instruments and assist in making the daily calculations necessary to conduct the survey, spent 3 months assisting Ellicott.

While engaged with the survey expedition and following his return to his farm, Banneker conducted the necessary astronomical observations to calculate an ephemeris for 1792. With the assistance of the Ellicotts, he succeeded in having the ephemeris published in the form of an almanac.

In 1791, Banneker wrote a letter to then US Secretary of State Thomas Jefferson in which he enclosed a manuscript copy of his ephemeris for 1792. His correspondence concerned Jefferson's published opinions on the alleged mental inferiority of Negroes as presented in his *Notes on the State of Virginia*, which had been published in 1788. Banneker offered his own accomplishments as evidence of the equal mental abilities of blacks and whites. Banneker's 1793 almanac published a copy of this letter as well as Jefferson's reply. Jefferson, for his part, sent the almanac to the secretary of the French Royal Academy as evidence of the mental abilities of Negroes.

From 1792 to 1797, Banneker calculated ephemerides for six separate almanacs that were published in various cities in 28 editions. Pertaining to the mid-Atlantic region, in addition to astronomical observations these almanacs included practical advice for farmers, notations of holidays, general forecasts of weather trends, and miscellaneous writings by Banneker and his contemporaries.

During his later life, Banneker devoted less time to farming and began leasing and selling small plots of his farm. In 1799, he legalized an informal arrangement to sell his remaining land to the Ellicotts in exchange for an annuity and life tenancy on the farm. He continued his astronomical observations and some routine farming chores as late as 1803, despite his failing health. Just shy of his 75th birthday, Banneker died at his farm in Baltimore County, Maryland. The site of his house, which is said to have burned to the ground on the day of his funeral, has been rediscovered near Oella, Maryland, and preserved by Baltimore County as a park dedicated to his memory.

Robert J. Hurry

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Banū Mūsā

Jaʿfar Muḥammad

Born **Baghdad, (Iraq), beginning of the 9th century**
Died **January or February 873**

Abū al-Qāsim Aḥmad

Born **Baghdad, (Iraq), beginning of the 9th century**
Died **Baghdad, (Iraq), 9th century**

Ḥasan

Born **Baghdad, (Iraq), beginning of the 9th century**
Died **Baghdad, (Iraq), 9th century**

The three brothers, the three sons of Musā ibn Shākir, generally known under the single name of the Banū Mūsā, were among the most important scientists of Baghdad in the 9th century; they played a prominent role as private patrons of scientific translations and research, and excelled in the fields of astronomy, mechanics, and mathematics.

It is quite impossible to write separate biographies of them. Their father, Mūsā ibn Shākir, is described as a reformed bandit who became a renowned astronomer or astrologer and a close friend of **Ma'mūn** (reigned: 813–833) before he was a caliph, while residing in Marw in Khurāsān. After Mūsā's death, the brothers became the wards of Ma'mūn, who cared for their education and sent them to the House of Wisdom (*Bayt al-ḥikma*), which was the major scientific institution in his time. After finishing their education, the Banū Mūsā collaborated with Ma'mūn and his successors in a variety of activities, which ranged from scientific matters (such as geodetic surveys) to managerial affairs (such as contracting for the building of public works and structures), thus becoming wealthy and powerful. This allowed them to devote a great deal of their acquired fortune to sponsoring scientific research. They actively sought classical works by ancient writers and sent agents or went themselves to Byzantium to purchase manuscripts that they translated on returning to Baghdad. On one such trip, Muḥammad met the famous mathematician and translator **Thābit ibn Qurra** of Ḥarrān and brought him back to Baghdad, where Thābit joined the circle of scientists and translators who were working under the patronage of the Banū Mūsā. The Nestorian Christian Ḥunayn ibn Isḥāq (died: *circa* 877), considered one of the most prolific and significant translators of 9th-century Baghdad, was also part of the Banū Mūsā team. In sum, these brothers promoted to a great extent the movement of translations that made it possible to assimilate the main classical scientific works into Arabic. Their significance to science and astronomy is not limited to this sponsorship of translations alone; like the scholars gathered around them, the Banū Mūsā also authored very important original scientific works of which there is a known list of some 20 books on astronomy, mechanics, and mathematics.

Almost a dozen of the works attributed to the Banū Mūsā are related to astronomical research. Muḥammad, the eldest son, wrote a treatise *On the Visibility of the Crescent*, a *Book on the Beginning of the World*, and a book variously known under the titles of *Book on the Motion of Celestial Spheres* (*Kitāb Ḥarakāt al-aflāk*), *Book of Astronomy* (*Kitāb al-Hay'a*), or *Book on the First Motion of the Celestial Sphere* (*Kitāb Ḥarakāt al-falak al-ūlā*), which contains a critique of the Ptolemaic system of the Universe. In it Muḥammad explains the daily motion of the heavens by the rotation of all the spheres of the Sun, the Moon, the five planets, and the fixed stars, denying the existence of the 9th sphere, which is the origin of movement in **Ptolemy**. Aḥmad is reportedly the author of a *Book on the Mathematical Proof by Geometry That There Is Not a Ninth Sphere Outside the Sphere of the Fixed Stars*, two texts on two questions that he discussed with his contemporary **Sanad ibn ˁAlī**, and a *zīj* (astronomical handbook), which is mentioned by the Egyptian astronomer **Ibn Yūnus**, who also says that there is another *zīj* by the three brothers. Finally, listed under the name of the Banū Mūsā are: A *Book of Degrees on the Nature of Zodiacal Signs*, regarding which it is stated in the manuscript that it is a translation of a Chinese work; a *Book on The Construction of the Astrolabe*, quoted by **Bīrūnī**; and, a *Book on the Solar Year.* The latter has traditionally been attributed to Thābit ibn Qurra, but recent research has shown that this is most likely a misattribution and that the treatise is actually by the Banū Mūsā. The majority of these books are now lost; however, the list of titles and the studies on the extant works show that the Banū Mūsā dealt extensively with the major concerns of astronomy in their time. Moreover, the interest of the Banū Mūsā in astronomy is also attested by reports that the brothers were involved in various activities, such as leading the astronomical observations that were made in Baghdad during the course of the 9th century or collaborating in the expeditions mounted by Ma'mūn for the purpose of making a geodetic measurement of the length of a degree along a terrestrial meridian.

The Banū Mūsā produced major work in the field of mechanics. Their efforts show important advances over those of their Greek predecessors: writers such as Philo of Byzantium (end of third century BCE) and Hero of Alexandria (middle of first century), whose works were extensively known by Muslim engineers. The Banū Mūsā also wrote many works in the field of mathematics, many devoted to geometrical problems. One of their most important works, *Book on the Measurement of Plane and Spherical Figures*, was the object of a recension by **Naṣīr al-Dīn al-Ṭūsī** in the 13th century and of a Latin translation by **Gerard of Cremona** in the 12th century under the titles *Liber trium fratrum de geometria* and *Verba filiorum Moysi filii Sekir*. This treatise was one of the fundamental texts on geometry in the Middle Ages, and its contents (in both the Arabic and European contexts) are found in authors such as Thābit ibn Qurra, **Ibn al-Haytham**, Leonardo Fibonacci of Pisa (died: 1250), Jordanus de Nemore (died: 1260), and **Roger Bacon** (died: *circa* 1292). The other works on geometry attributed to the Banū Mūsā are three books related to the *Conic Sections* of **Apollonius of Perga** (third century BCE), a *Book on a Geometric Proposition Proved by Galen*, a *Reasoning on the Trisection of an Angle* (by Aḥmad), and a *Book on an Oblong Round Figure.* The latter concerns the ellipse and contains a description of what is known as the gardener's construction, a procedure for drawing an ellipse by means of a string fastened to two pegs and based on the fact that the sum of the two focal radius vectors of any point belonging to a given ellipse is constant.

Finally, the family tradition of the Banū Mūsā seems to have been continued to a certain extent by a son of the eldest brother, Nuˁaym ibn Muḥammad ibn Mūsā, who wrote *Book on Geometric Propositions*.

Josep Casulleras

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Bär, Nicholaus Reymers

Flourished **Prague, (Czech Republic), 1584**

Itinerant German Nicholaus Bär seems to have plagiarized most of his cosmological ideas from **Tycho Brahe**. However, in his variation of the Tychonic system, Mars' orbit enclosed that of the Sun. Brahe replaced Bär as imperial mathematician.

Alternate name

Raimarus Ursus

Selected Reference

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Barbier, Daniel

Born **Lyon, France, 10 December 1907**
Died **Marseilles, France, 1 April 1965**

French observational astronomer Daniel Barbier made his most significant contributions to the study of the background light of the night sky. His student, G. Weill, also worked in this area. Along with **Daniel Chalonge**, Barbier set up the first quantitative, three-dimensional system of photometric classification of stars (further described in the article on Chalonge). He was the theoretician of the pair, responsible for a textbook on stellar atmospheres and for the definition of the parameter in the classification system that describes the chemical composition of the stars. After World War II, Barbier turned his attention to the night skylight, especially the 6,300 Å forbidden line of neutral oxygen and the variations of its strength and the height of the level in the atmosphere (the F layer of the ionosphere) where it is emitted. He died just at the end of an observing run at Observatoire de Haute-Provence.

Roger Cayrel

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Barhebraeus: Gregory Abū al-Faraj

Born **Malaṭya, (Turkey), 1225/1226**
Died **Marāgha, (Iran), 29/30 July 1286**

Barhebraeus, a Syrian (or Syriac) Orthodox ("Jacobite") prelate and polymath, is the foremost representative of the "Syriac Renaissance" of the 12th and 13th centuries. He was also closely associated with several members of the "Marāgha School" of astronomers, and he wrote several works dealing with various aspects of astronomy.

Barhebraeus' birthplace of Malaṭya (or Melitene) was at the time under the rule of the Saljūqs of Rūm (Asia Minor), a Turkish–Islamic dynasty. It had an important community of Syrian Orthodox Christians that included Barhebraeus' family. His father Aaron (Ahrōn) was a physician. The view that links the name Barhebraeus to a Jewish ancestry is best rejected in favor of one linking it to the village of ʿEḇrā on the Euphrates, downstream of Melitene. After periods of study in Antioch, Tripoli (both then still in the hands of the Crusaders), and possibly Damascus, he was raised to the episcopate at the age of 20 in 1246 and was appointed, successively, to the sees of Gubos and Laqabin in the vicinity of Melitene. Sometime around 1253, Barhebraeus was transferred to Aleppo, where he would witness the fall of the city to the Mongols in 1260. In 1264, he was raised to the office of the Maphrian of the East, the second highest office in the Syrian Orthodox Church with jurisdiction over an area roughly coinciding with today's Iraq and Iran. His normal place of residence as Maphrian was Mosul and the nearby monastery of Mar Mattai, but a significant part of his maphrianate was spent in Marāgha and Tabrīz, the new centers of power under the Mongol īlkhānids.

Barhebraeus composed over 40 works covering a diverse range of subjects, most of which are in Syriac, although some are in Arabic. Typical of Barhebraeus is the manner in which he takes an Arabic (occasionally Persian) work as his model and structures his own work around it. He then incorporates into this framework materials taken from both Arabic and Syriac sources, thus making a new synthesis out of older Syriac and more recent Arabic materials. In his philosophical works he is influenced by **Ibn Sīnā**, while in his moral-mystical theology he stands under the influence of Al-Ghazālī (died: 1111), the preeminent Islamic theologian, jurist, and Sufi.

Barhebraeus' interest in astronomy and related sciences is likely to have been prompted by his acquaintance with **Naṣīr al-Dīn al-Ṭūsī** and other scholars gathered around the newly founded observatory and library in Marāgha. Evidence for this is provided by a manuscript of a collection of mathematical texts revised by Ṭūsī, which was once in Barhebraeus' possession and bears his signature (today in Istanbul-Üsküdar, Selim Ağa MS 743). We are also told by Ḥājjī Khalīfa that **Ibn Abī al-Shukr al-Maghribī**, one of Ṭūsī's collaborators, composed an epitome of **Ptolemy**'s *Almagest* at Barhebraeus' behest (*Kashf al-ẓunūn*, Vol. 5, pp. 387, 389).

Barhebraeus' major work in the field of the exact sciences is the *Ascent of the Mind* (*Sullāqā hawnānāyā*), a textbook of astronomy and mathematical geography composed in 1279 and modeled on Ṭūsī's *Tadhkira fī ʿilm al-hayʾa*, but incorporating materials taken from other sources. Especially for his Syriac terminology, Barhebraeus must have been dependent upon earlier Syriac works, among them the works of **Severus Sebokht**, who is mentioned by name at one point (Nau, p. 106f.).

The lists of Barhebraeus' works mention a work, now lost, called "Astronomical tables (*zīj*) for Beginners," composed, according to the older manuscript witnesses of the lists (Vatican, Borgia syr. 146 and Florence, Laur. or. 298), in Arabic. It is unclear what exactly Barhebraeus means when he tells us in his *Chronicon ecclesiasticum* (II.443.1f., 443.19f.) that he "solved/explained" (*shrā*, corresponding to Arabic *ḥalla*) the "Book of Euclid" (*i. e.*, the *Elements*) in Marāgha in 1267/1268 and Ptolemy's *Almagest* similarly in Marāgha in the summer of 1272. Perhaps the meaning is "lectured on" or simply "studied." It is unlikely, at any rate, that it involved the composition of written works.

Astronomy and related disciplines occasionally play a role in Barhebraeus' other works, as in the second part ("On Creation," composed *circa* 1267) of his major theological work, the *Candelabrum of the Sanctuary* (*Mnāraṯ quḏshē*). The principal source for the parts of this work dealing with mathematical geography, astronomy, and chronology is **Bīrūnī**'s *Kitāb al-tafhīm li-awā'il ṣināʿat al-tanjīm*; here too, Barhebraeus has used a number of additional sources, as may be seen from the fact that the values given for the latitudes of the seven climes are neither those given in Bīrūnī's *Tafhīm* nor those in Ṭūsī's *Tadhkira* (which Barhebraeus later adopted in the *Ascent of the Mind*) but the traditional values as given in the *Almagest*. Traces of Severus Sebokht's works are found again among the newly added materials in Barhebraeus' later, shorter work on theology, the *Book of Rays* (*Kṯāḇā d-zalgē*), which is otherwise largely a summary of the *Candelabrum*.

Barhebraeus' historical works are of interest to the historian of science for the information they provide on earlier scholars and have frequently been used for this purpose since the first publication of his Arabic history, the *Mukhtaṣar ta'rīkh al-duwal*, in 1663. While the publication of those works used as sources by Barhebraeus (*e. g.*, Qifṭī and **Ṣāʿid al-Andalusī**) has diminished the value of Barhebraeus' works in this respect, there are instances where he reveals his knowledge of older Syriac sources inaccessible to Arabic historians. One example is the passage on the trepidation of the fixed stars taken from **Theon of Alexandria**'s *Small Commentary on the Handy Tables* (in Barhebraeus' Syriac *Chronicon*; also in the *Ascent of the Mind* and his major philosophical work, the *Cream of Wisdom*/*Ḥēwaṯḥeḵmṯā*).

Hidemi Takahashi

Alternate names

Grīḡōriyōs Bar ʿEḇrāyā
Grīḡōriyōs Bar ʿEḇroyo

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Bar Ḥiyya: Abraham Bar Ḥiyya Savasorda

Born **Barcelona, (Spain), 1070**
Died **1136**

Bar Ḥiyya is credited with writing the first works in Hebrew on astronomy and mathematics. He held several official positions in Barcelona, although that city was under Christian control. Bar Ḥiyya was fluent in Arabic, the leading language of science at the time. In response to requests from his Jewish coreligionists in Provence, Bar Ḥiyya produced a series of Hebrew texts in astronomy and mathematics, the first of their kind to be written in that language. He also created an entirely new Hebrew technical terminology. His *Ṣurat ha-Aretz* (Form of the earth) is a representative of a nontechnical exposition of astronomy genre that was immensely popular in the medieval period, especially among the Hebrew reading public. Bar Ḥiyya also compiled a set of tables, known as Luḥot ha-Nasi (Nasi being one of the titles borne by Bar Ḥiyya) or the Jerusalem Tables. These tables are for the most part based upon the tables of **Battānī**. However, some manuscripts (for example, Chicago, Newberry College, MS. Or 101) have appended to them a set of short essays and accompanying tables. These addenda have never been properly studied; one of them, which investigates the differences between the tables of **Ptolemy** and Battānī, may be of particular interest. Bar Ḥiyya's tables were later used by **Abraham ibn ʿEzra**; some manuscripts, such as the one just mentioned, bear tables of Ibn ʿEzra as well as some glosses by students of the latter.

Y. Tzvi Langermann

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——— (2000). "Hebrew Astronomy: Deep Soundings from a Rich Tradition." In *Astronomy Across Cultures*, edited by Helaine Selin, pp. 555–584. Dordrecht: Kluwer Academic Publishers. (Discussion of utilization of Bar Ḥiyya's tables by Ibn ʿEzra and his students.)

Barker, Thomas

Born **Lyndon, Leicestershire, England, 1722**
Died **Lyndon, Leicestershire, England, 29 December 1809**

Besides being a noted vegetarian, Thomas Barker is known primarily for his catalog of comets and their orbital elements. Inspired by the cometographic theories of his grandfather **William Whiston**, Barker investigated comets and provided a handy table for determining parabolic trajectories and orbits.

Marvin Bolt

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Poggendorff, J. C. (1863). "Barker." *Biographisch-literarisches Handwörterbuch*. Vol. 1, col. 101. Leipzig: J. A. Barth.

Barnard, Edward Emerson

Born **Nashville, Tennessee, USA, 16 December 1857**
Died **Williams Bay, Wisconsin, USA, 7 February 1923**

As both a visual and a photographic observer who made a multitude of discoveries that of extended interstellar absorption regions, or dark nebulae, being perhaps the most important, Edward Barnard became one of the greatest astronomers of his time, but his beginnings were extremely humble. He was born into impoverished circumstances just before the American Civil War. After his father, Reuben Barnard, died 3 months before Edward was born, his mother, Elizabeth Jane (*neé* Haywood) Barnard, who was already 42, raised him and his elder brother Charles (who seems to have been feeble-minded) by herself. Elizabeth's broad literary interests are attested by the unusual middle name she chose for her second son, that of American writer and philosopher Ralph Waldo Emerson. She taught Edward to read, mainly from the Bible; otherwise Barnard had only 2 months of formal schooling.

At the tender age of nine, just after the Civil War ended and with Nashville under occupation by Union troops, Barnard's mother sent him to work in the photograph gallery of John H. Van Stavoren. As his first assignment, Barnard guided a large "solar camera" ("Jupiter") on the Sun. Jupiter provided intense light for portrait enlarging in that slow, wet-plate era. Barnard performed these humble duties well, and advanced to doing other photographic work, thus gaining broad experience in photographic techniques that he later put to spectacular use as an astronomer. Several of Van Stavoren's assistants, notably James W. Braid, who had wide-ranging interests in electricity and other technical matters, and Peter and Ebenezer Calvert, native Yorkshire men who were employed as artists at the studio, supported young Barnard intellectually and emotionally during this time. By now, Barnard's mother was an invalid, and he had become the sole provider for the family. The Calverts introduced Barnard to their sister, his future wife, Rhoda.

As a young child, Barnard had a naive interest in the stars, watching them passing overhead from a small wagon in his yard. He recalled seeing one of the great comets that appeared during the Civil War. At the age of 18, he received by chance a book on astronomy, loaned to him as the surety of a small loan from an acquaintance he suspected had stolen it; he never saw the acquaintance again. The book, *The Practical Astronomer* by Reverend **Thomas Dick**, a Scottish writer of sermons and "moral and religious reflections" on astronomy, contained star charts from which Barnard identified the constellations of the Summer Triangle. His interest piqued, Barnard acquired, with Braid's help, a 2-in. telescope, with which – in the spring of 1876 – he observed the phases of Venus and the satellites of Jupiter. The impression they made, he later noted, was "more profound and pleasing … than the celebrated discovery of the fifth satellite of Jupiter."

In 1877, Barnard acquired a 5-in. refractor for $380 – two-thirds of his annual salary at the photography studio – with which he began to make a serious study of the sky. The American Association for the Advancement of Sciences held its annual meeting in Nashville that year. At the meeting, Barnard introduced himself to America's leading mathematical astronomer, **Simon Newcomb**, asking him what useful work might be done by a young man with a telescope. Newcomb responded, "put away that telescope and study mathematics." Barnard was devastated, but soon recovered. He married Rhoda Calvert, who was 37 at the time, he was 23. While working at the photography studio during the day, Barnard searched diligently for comets at night, lured by a cash award of $200 for each comet discovery offered by patent-medicine vendor H. H. Warner of Rochester, New York. Barnard became one of the most successful visual comet seekers of all time. He discovered his first comet in 1881 (now designated C/1881 S1). His eventual record of 16 new comets and three recovered periodic comets was surpassed only by that of **William Brooks**, his contemporary, and the legendary **Jean Pons** of the Marseilles Observatory, who observed during Napoleon's time.

The Warner comet discovery prizes helped Barnard to obtain the mortgage for a small lot in a not-very-desirable part of Nashville, where he built a house, which became known as Comet

House. Here Barnard and Rhoda lived until, in 1883, largely owing to the recognition for his comet discoveries, he received a fellowship to Vanderbilt University and moved to university-provided housing on campus.

Barnard remained at Vanderbilt until 1888, when he moved to Lick Observatory as one of its original staff astronomers. At that time Lick Observatory possessed the world's most powerful telescope, the 36-in. Clark refractor. In addition to West Point trained observatory director **Edward Holden**, the Lick Observatory staff included pioneer spectroscopist **James Keeler** and double-star observer **Sherburne Burnham**, who became a father figure and mentor to Barnard. At Lick, Barnard was at first encouraged to continue his comet seeking, and he made visual observations, especially of the planets, with the 12-in. Clark refractor.

Among Barnard's most remarkable feats was his 1 November 1889 observation, with the 12-in. Clark, of the eclipse of Saturn's satellite Iapetus by the shadow of the crepe ring. This event, which was not recorded anywhere else – and specifically, not with the 36-in. refractor, which Holden, as was his custom, shut down early that night – triggered indignant comments from other astronomers on the use of that great instrument, and ignited a smoldering disagreement between Holden and Barnard. Holden did not allow Barnard to use the 36-in. refractor on a regular basis; this led to a long, unseemly, and bitter argument between the director and the assistant astronomer. In the end, Barnard would be vindicated; but by barring him from the large telescope, Holden had unwittingly played up the circumstances of deprivation of Barnard's emotionally scarred childhood. There were times when Barnard – always high-strung and overwrought – came close to suffering a nervous breakdown. Barnard finally took his case directly to the Regents of the University of California, and they ruled in his favor.

Beginning in August 1892, Barnard was given the great telescope to use every Friday night, and within a month – on 9 September 1892 – he galvanized the astronomical world and the wider public by discovering the fifth satellite of Jupiter. **Camille Flammarion** recommended the name Amalthea, after the nurse of Jupiter, for the new satellite, but Barnard disliked that name and continued to refer to it only as "the fifth satellite."

Barnard recorded some of the most extraordinary drawings of Mars ever made during its 1892 and 1894 oppositions, with the 36-in. refractor. His drawings did not support the view of a canal crisscrossed planet then being promoted by the controversial planetary astronomer **Percival Lowell**, but few of Barnard's drawings were ever published.

Meanwhile, Barnard was pursuing another front line of research. Beginning in August 1889, he used a 6-in. Willard portrait lens to obtain wide-angle photographs of comets and the Milky Way. By 1895, Barnard had obtained scores of images revealing both the structure of comet tails and hitherto unknown dark markings in the Milky Way. Barnard initially believed that the dark markings of the Milky Way were chasms, regions of vacancy, among the stars. However, the English astronomer **Arthur Ranyard**, who published Barnard's photographs in the journal *Knowledge*, disagreed with Barnard. "The dark vacant areas or channels …" Ranyard wrote, "seem to me to be undoubtedly dark structures, or absorbing masses in space." Ranyard died soon thereafter, and the whole issue remained unresolved, but continued to nag Barnard for years.

In 1895, Barnard left Mount Hamilton, and his troubled relationship with Holden, to join **George Hale** and the University of Chicago's Yerkes Observatory with its 40–in. Clark refractor, at Williams Bay, Wisconsin. At Yerkes, Barnard initially worked very hard, just as he had at Lick and at Vanderbilt. He was a remarkably versatile observer, known for his keen eye, his skill with the micrometer, and, above all, his abilities with the photographic plate and in the darkroom. His work is not easily summarized, since there was hardly anything in the heavens that did not interest him; he was "an observer of all that shines – or obscures." Hale gave him two nights a week on the 40-in. refractor, and he used every scrap of clear night – summer and winter – on it and other telescopes without respite. When a visitor asked how he kept warm in the unheated dome, during the cold nights of winter in Wisconsin, he replied: "We don't!"

Barnard left the Willard lens with which he had pioneered the photography of the Milky Way in California. However, he was able to obtain funding, from a reclusive New York heiress, Catherine Bruce, for a better instrument – the 10-in. Bruce photographic telescope – that he mounted in a tin dome on the grounds at Yerkes by 1904. A year later, Hale, seeking clearer and sunnier skies, started to transfer his astronomical base to Mount Wilson, near Pasadena. The master fund-raiser obtained a grant to allow Barnard to ship the Bruce telescope to Mount Wilson at the beginning of 1905, so that he could use it to photograph the more southerly portions of the Milky Way.

Over a period of 8 months, Barnard – keeping hours that would have "horrified any medical man" – obtained 500 plates, which would form the basis of his *Atlas of Selected Regions of the Milky Way*. The plates are masterpieces showing detail that helped Barnard decide that the dark areas were indeed clouds of obscuring matter between the stars. The final epiphany came, however, on a clear transparent moonless night in the summer of 1913 when Barnard observed a group of ordinary cumulus clouds standing silhouetted and inky-black against the great Sagittarius star clouds. He cataloged many of the more prominent dark masses of the Northern Milky Way, which continue to be referred to by their Barnard catalog numbers.

Barnard began to suffer from diabetes in 1914, and in later years he was in failing health. He knew that his greatest legacy to astronomical science was his photographic catalog of the Milky Way. He struggled to find a collotype or photogravure process that would do justice to those images, but finally refused to compromise on his masterpiece. Instead he decided to use actual photographic prints, and personally inspected each of them, 35,000 in all, to make sure they achieved his standard. Unsurprisingly, the work was not completed in his lifetime. It appeared 4 years after his death, having been completed by **Edwin Frost**, who had succeeded Hale as director of Yerkes, and Barnard's niece, Mary Calvert, who had served as his personal assistant.

As a self-made man himself, and a perfectionist who believed he could more easily do by himself than teach another to do for him, Barnard never had formal students. Nevertheless, he was a generous correspondent with students and schoolboys, encouraging them in their own efforts to become astronomers.

Over the course of his career, Barnard was honored frequently for his contributions to astronomy. In addition to the five Warner Prizes and three Donohue Comet Medals he received for his comet discoveries, Barnard received the Lalande, Arago, and Janssen Gold Medals and prizes from the French Academy of Sciences and

French Astronomical Society. He was awarded the Gold Medal of the Royal Astronomical Society and the Bruce Gold Medal from the Astronomical Society of the Pacific. He was elected to the American Academy of Arts and Sciences and the National Academy of Sciences and was a foreign associate of the Royal Astronomical Society. Vanderbilt University conferred an honorary D.Sc. on Barnard for his achievements after leaving that institution.

Three archives have significant Barnard holdings, including manuscripts, notebooks, and his extensive correspondence with astronomers of his time: the Joseph Heard Library of Vanderbilt University, the Mary Lea Shane archives of the Lick Observatory, and the library of the Yerkes Observatory.

William Sheehan

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Sheehan, William (1995). *The Immortal Fire Within: the Life and Work of Edward Emerson Barnard*. Cambridge: Cambridge University Press.

Barnothy, Jeno M.

Born **Kassa (Košice, Slovakia), 28 December 1904**
Died **Evanston, Illinois, USA, 11 October 1996**

Cosmologist Jeno Barnothy received his Ph.D. in 1939 from the Peter Pazmany (now Lorand Eötvös) University in Budapest, Hungary, for work on cosmic-ray physics, carried out with **MadeleineBarnothy Forro.** (They married in 1938.) He was associated with that university from 1935 to 1948, receiving awards from the Hungarian Academy of Sciences in 1939 and 1948. The cosmic-ray work, partly carried out in the Dorog coal mine near Budapest, led to the establishment of a small group of students working in the field. Most of them turned their attention to other fields when cosmic-ray physics could not be reestablished in Hungary after World War II. The best-known is Ervin J. Fenyves, a relativist at University of Texas, Dallas.

After moving to the United States, the Barnothys were associated first with Barat College (Lake Forest, Illinois) and later with Northwestern University in Evanston, primarily in the medical school, where they taught some physics and some biophysics.

The Barnothys' later work was in cosmology and astrophysics. His nonconventional ("FIB") cosmology is not much remembered, but the suggestion (partially endorsed by the younger astrophysicist, Beatrice M. Tinsley) that gravitational lensing might be important to the appearance of quasars and active galaxies is still sometimes cited.

Virginia Trimble

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Fenyves, Ervin J. and Antal Somogyi (1997). "Jeno M. Barnothy, 1904–1996." *Bulletin of the American Astronomical Society* 29: 1467–1468.

Barnothy Forro, Madeleine

Born **(Hungary), 21 August 1904**
Died **Evanston, Illinois, USA, March 1993**

Madeleine Forro participated in the construction of large Geiger–Müller counters and one of the first underground cosmic-ray "telescopes," suitable for study of the very high-energy spectrum, isotropy, temporal variability, and absorption of cosmic rays in the atmosphere.

Forro carried out her Ph.D. research at the Institute for Experimental Physics of the Peter Pazmany (now Lorand Eötvös) University in Budapest, Hungary, receiving her degree in 1928 for work on measurements of dielectric constant. That year, she began work in cosmic-ray physics with **Jeno Barnothy**. (They married in 1938.)

After failing at an effort to reestablish cosmic-ray physics in Hungary after World War II, the Barnothys left for the United States, crossing the border in the trunk of a car and living on nothing but potatoes in a cellar for a week.

The two astronomers turned their attention partly to astrophysics, putting forward an unconventional cosmology (in which photons might circle a closed universe, returning as cosmic rays) and the idea that quasars were gravitationally lensed images of Seyfert galaxies. The latter is approximately correct, in the sense that a small fraction of quasars (at large redshift) do indeed appear brightened by lensing.

Barnothy Forro held positions at Barat College (Lake Forest, Illinois), Northwestern University (Evanston, Illinois), and the University of Illinois Medical School at Chicago. Some of these positions were connected with the Barnothys' interests in biophysics, particularly the effects of strong magnetic fields on mammals.

Virginia Trimble

Selected Reference

Fenyves, Ervin J. and Antal Somogyi (1995). "Madeleine Barnothy Forro, 1904–1993." *Bulletin of the American Astronomical Society* 27: 1475.

Baron Blackett of Chelsea

➔ **Blackett, Patrick Maynard Stuart**

Baron Kelvin of Largs

Thomson, William

Barozzi, Francesco

Born **Candia (Iráklion), Crete, (Greece), 9 August 1537**
Died **Venice, (Italy), 23 November 1604**

Francesco Barozzi is important to the history of astronomy both for his attempts to reform the teaching of astronomy and in his advocacy of the value of mathematics and mathematical sciences.

Barozzi was born into a noble Venetian family with extensive holdings in Rettimo (modern Rethymnon) in Crete, and spent many years of his life there on family business. He received a humanistic education culminating in the University of Padua, where Barozzi studied mathematics and philosophy. By 1559, he was lecturing there on the *Sphere* of **John of Holywood.** Barozzi actively labored in the Renaissance effort to recover classical texts and study them critically. In that spirit he searched for, collected, copied, edited, translated, and (in some cases) also published ancient Greek mathematical works, including those of **Proclus**, Hero, **Pappus**, and **Archimedes**. Barozzi possessed one of the finest collections in his era of ancient manuscript texts on mathematical topics, and actively patronized the activity of others. He also published an original work on the geometry of parallel lines and a cosmography intended to replace Sacrobosco's *Sphere.* (See below.) Barozzi's interests extended well beyond mathematics to include dabbling in astrology, natural magic, and sorcery. He was tried, convicted, and penalized by the Venetian Inquisition at least once, in 1587, for a variety of conjurations in Crete, inspired, apparently, by his reading of Cornelius Agrippa and Peter d'Abano. (He was condemned and confined by the Holy Office on at least one other occasion for unknown reasons.) Though Barozzi regained his freedom by 1588, he published little during the rest of his life.

In publishing his *Cosmographia* (Venice, 1585, 1598, and translated into Italian, 1607), Barozzi attempted to replace what he saw as a flawed basis for astronomical teaching, namely the venerable *Sphere* of Sacrobosco and the commentaries on it. His new text corrected, so he claimed, the numerous errors of the old, and Barozzi devoted many pages of his text to listing and explaining these errors (most of which were procedural or didactic in nature). His criticisms provoked an amicable exchange of correspondence with **Christoph Clavius**, author of one of the foremost contemporary *Sphere* commentaries. Though Barozzi offered no important corrections or innovations to the subject matter of astronomy itself, his attempts at reform are a further example of the strength of the sentiments for such change in the middle and late 16th century, and especially in the ambit of the University of Padua. In an era when the value of teaching mathematical subjects and the status of mathematical sciences themselves were being called into question (usually by Aristotelian philosophers such as **Alessandro Piccolomini**), Barozzi defended not only the utility of mathematics, but also the suitability of mathematical methods for investigating and reasoning about nature.

James M. Lattis

Alternate name

Franciscus Barocius

Selected References

Boyer, Marjorie Nice (1970). "Barocius, Franciscus." In *Dictionary of Scientific Biography*, edited by Charles Coulston Gillispie. Vol. 1, p. 468. New York: Charles Scribner's Sons.

Giacobbe, Giulio Cesare (1972). "Francesco Barozzi [1537–1604] e la *Quaestio de certitudine mathematicarum*." *Physis* 14: 357–374.

Rose, Paul Lawrence (1977). "A Venetian Patron and Mathematician of the Sixteenth Century: Francesco Barozzi (1537–1604)." *Studi Veneziani, n.s.,* 1: 119–178. (This is the best treatment of Barozzi; it includes a complete bibliography of primary sources and also prints a number of his letters.)

Spiazzi, G. (1964). "Barozzi, Francesco." In *Dizionario biografico degli italiani*. Vol. 6, pp. 495–499. Rome: Istituto della Encicilopedia italiana.

Barringer, Daniel Moreau

Born **25 May 1860**
Died **30 November 1929**

American mining engineer Daniel Barringer correctly claimed that a crater in northern Arizona was the result of impact. He drilled in vain, hoping to discover a large mass of metal ore that he could exploit economically.

Selected Reference

Hoyt, William Graves (1987). *Coon Mountain Controversies: Meteor Crater and the Development of Impact Theory*. Tucson: University of Arizona Press.

Bartholin, Erasmus

Born **Roskilde, Denmark, 13 August 1625**
Died **Copenhagen, Denmark, 4 November 1698**

Erasmus Bartholin was a transitional figure in Danish astronomy. He edited works of **Tycho Brahe** and taught **Ole Römer**. Foremost a physician, Bartholin observed the comet of 1665 (C/1665 F1). He is better known for describing the optical phenomenon of double refraction.

Selected Reference

Christianson, John Robert (2000). *On Tycho's Island: Tycho Brahe and His Assistants, 1570–1601*. Cambridge: Cambridge University Press.

Bartholomaeus Anglicus

Flourished **Paris, France 13th century**

Bartholomaeus Anglicus's early encyclopedia, *De Proprietatibus Rerum*, was (in the words of philologist S. K. Heninger, Jr.) "… a monument of erudition that transmitted intact the medieval worldview to the Renaissance."

Selected Reference

Anon. (1977). *The Cosmographical Glass*. San Marino, California: Huntington Library.

Bartsch, Jakob

Flourished **(Poland), 1624**

Either **Johann Bayer** or uranographer Jakob Bartsch is responsible for introducing Musca, one of the most obscure modern constellations.

Alternate name

Bartschius

Selected Reference

Sesti, Giuseppe Maria (1991). *The Glorious Constellations: History and Mythology*. New York: Harry N. Abrams.

Bartschius

➔ **Bartsch, Jakob**

Bāṣo

➔ **Ibn Bāṣo: Abū ʿAlī al-Ḥusayn ibn Abī Jaʿfar Aḥmad ibn Yūsuf ibn Bāṣo**

Basṭūlus

➔ **Nasṭūlus: Muḥammad ibn ʿAbd Allāh**

Bates, David Robert

Born **Omagh, Northern Ireland, 10 November 1916**
Died **Belfast, Northern Ireland, 5 January 1994**

Sir David Bates carried out innovative research in atomic, molecular, and optical physics, which he applied to problems of aeronomy and astronomy. He was educated at the Royal Belfast Academic Institution in Belfast, after which he entered the faculty of science of the Queen's University of Belfast. He graduated in 1937 with B.Sc. degrees in experimental physics and mathematical physics, obtaining first-class honors in both. In 1938, Bates was awarded the M.Sc. degree. He married Barbara Morris in 1956, and they had two children, Kathryn Maud and Adam David.

After wartime research and before departing for Belfast in 1951, Bates was lecturer in the Department of mathematics and then reader in the Department of Physics at University College London. He was professor and head of the Department of Applied Mathematics of the Queen's University of Belfast from 1951 to 1973, and then occupied a special research chair until 1982, when he became professor emeritus. During his tenure in the Department of Applied Mathematics (later the Department of Applied Mathematics and Theoretical Physics), Bates built a research school in atomic, molecular, and optical physics that became world renowned.

With graduate students and postdoctoral fellows, Bates drew deep connections between atomic, molecular, and optical physics and astronomy. In his studies, Bates combined physical insight with mathematical formulations constructed so that numerical calculations could be carried out to enable quantitative comparisons to be made of theory and measurement. He investigated a diverse range of processes and made significant contributions to the accurate description of photoionization, photodetachment, collisional excitation, ionization and charge transfer, chemical reactions, mutual neutralization, radiative association, dissociative recombination, dielectronic recombination, collisional-radiative recombination, and ion–ion recombination. He profoundly influenced and inspired generations of graduate students.

Bates' applications to the terrestrial atmosphere established the foundation and fundamental concepts for later studies of the physics and chemistry of planetary atmospheres and astrophysical plasmas. His approach, first employed in studies of the terrestrial ionosphere, has become standard. In it, he identified the detailed microscopic processes that produced the free electrons and the recombination processes that removed them, made estimates of their rates, and evaluated their consequences.

The original analysis of ionospheric structure with Sir Harrie Massey led to the recognition that the process they called dissociative recombination is the dominant recombination process in molecular plasmas, and Bates demonstrated that it plays a decisive role in determination of the luminosity and chemistry of many atmospheric and astrophysical environments and laboratory plasmas. Working with Marcel Nicolet, Bates identified the chemical source of the infrared hydroxyl bands in the airglow of the atmosphere and pointed to the importance of methane and water vapor in the chemistry of ozone.

With Agnes Witherspoon and Paul Hays, he demonstrated the profound effects of minor constituents in atmospheric chemistry and the role of industrial and microbiological sources and sinks. This research is fundamental to studies of global change and the effects of pollution.

Bates made substantial contributions to astrophysics, perhaps none more enduring than work with **Lyman Spitzer** on the formation and destruction of molecules in interstellar clouds. From 1962 to 1993 Bates was editor of *Planetary and Space Science,* and for 28 years he was a coeditor of *Advances in Atomic, Molecular and Optical Physics.*

Bates received many honors including election to the Royal Irish Academy in 1952, the Royal Society of London in 1958, the International Academy of Astronautics in 1961, the American Academy of Arts and Sciences in 1974, the Académie royale de Belgique in 1979, the United States National Academy of Sciences in 1984, and the International Academy of Quantum Molecular Science in 1985. He received honorary degrees from seven universities. He was awarded the Hughes Medal of the Royal Society in 1970, the Chree Medal of the United Kingdom Institute of Physics in 1978, the Gold Medal of the Royal Astronomical Society in 1979, and the Fleming Medal of the American Geophysical Union in 1987. For his services to science and education Bates was knighted in 1978. Two medals were created in his honor: the Sir David Bates Medal of the Európean Geophysical Society and the Sir David Bates Medal of the UK Institute of Physics.

Alex Dalgarno

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Bates, David R. (1983). “Scientific Reminiscences.” In *Proceedings of the International Symposium on Atomic, Molecular and Solid-State Theory, Collision Phenomena, and Computational Quantum Chemistry*, edited by Per-Olov Löwden, pp. 5–32. International Journal Of Quantum Chemistry, Quantum Chemistry Symposium, no. 17. New York: John Wiley and Sons.

Burke, P. G. and D. S. F. Crothers (1996). “Professor Sir David Bates, FRS.” *Comments on Atomic and Molecular Physics* 32: 127–130.

Dalgarno, Alexander (1997). “Sir David Robert Bates.” *Biographical Memoirs of Fellows of the Royal Society* 43: 47–71.

Bateson, Frank Maine

Born **Wellington, New Zealand, 31 October 1909**

Frank Bateson organized variable star observing in New Zealand, providing leadership to the field in the Southern Hemisphere for 78 years. The son of Charles and Alice Bateson, he was educated at the Hurworth Preparatory School in Wanganui, New Zealand, and at Scots College, Sydney, Australia, and undertook a career in business administration and accountancy.

After reading **Robert Ball**’s *Great Astronomers*, Bateson made his first observations of meteors in 1923 and then variable stars in 1924. He joined the British Astronomical Association’s New South Wales branch and was lent a small refractor and allowed to use the refractor at the Sydney Observatory. Bateson returned to New Zealand in 1927 and founded the Variable Star Section [VSS] of the New Zealand Astronomical Society (later the Royal Astronomical Society of New Zealand [RASNZ]). Under his leadership, the number of active observers increased as did the number and types of variable stars covered. Bateson established close working relationships with professional astronomers and provided them with data obtained by the RASNZ observers using over 1,000 charts of southern variable stars that Bateson published (most with Mati Morel). The approximately one million observations recorded by RASNZ observers during Bateson’s tenure as the VSS Director provided the basis for hundreds of publications.

In the late 1950s, Bateson promoted his vision of a professional observatory in New Zealand in collaboration with **Frank Wood** of the University of Pennsylvania. Bateson conducted an extensive site-testing program and recommended the site at Mount John. The Mount John Observatory was established with the University of Canterbury in 1965; Bateson served as its director until his retirement in 1969.

In 1931, Bateson married Doris McGoldrick; they had two daughters. Bateson was awarded the Jackson–Gwilt Medal and Prize of the Royal Astronomical Society in 1960, and an honorary doctorate from the University of Waikato in 1979. His autobiography, *Paradise Beckons*, was privately published in 1989.

Grant Christie

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Evans, R. W. (ed). (2005). *Southern Stars*. Wellington: Royal Astronomical Society of New Zealand. (Volume 44: number 1, pp. 1–40 contains papers from the Conference Celebrating Frank Bateson’s 80 Years of Astronomy, held 4 December 2004 at Tauranga, New Zealand.)

Battānī: Abū ʿAbd Allāh Muḥammad ibn Jābir ibn Sinān al-Battānī al-Ḥarrānī al-Ṣābiʾ

Born **Harran, (Turkey), before 858**
Died **near Samarra, (Iraq), 929**

Battānī was one of the most influential astronomers of the early Islamic period. He was particularly well known for the accuracy of his observations, which he carried out at Raqqa in northern Syria over a period of 40 years. He wrote an important astronomical handbook with tables (*zīj*) and some astrological treatises in the tradition of **Ptolemy**’s *Tetrabiblos*.

Battānī hailed from Harran in southern Anatolia, possibly from the district Battān of that city, which is mentioned by the famous 16th-century Egyptian scholar **Suyūṭī** in his lexicon of epithets of location, the *Lubb al-lubāb*. Battānī was born into a family of Sabians. Adherents of this pagan religion, mainly centered in Harran, were characterized by a type of star idolatry going back to Babylonian times, and included numerous prominent scholars such as **Thābit ibn Qurra**. From his first name Muḥammad and his *kunya* Abū ʿAbd Allāh, we see that Battānī himself was a Muslim. In European works up to the 19th century, Battānī was mistakenly presented as a noble, a prince, or a king, but there is no justification for such attributions in Arabic sources.

Battānī was probably the son of Jābir ibn Sinān al-Ḥarrānī, a well-known instrument maker from Harran mentioned by the earliest bibliographer of Muslim scientists, Ibn al-Nadīm (died: 990). So we may assume that Battānī learned about astronomical instruments from his father before he moved to Raqqa in northern Syria.

In Raqqa, Battānī devoted considerable financial resources to establish a private observatory at which he regularly conducted observations during the period from 877 to 918. Among the instruments that he is known to have used are a gnomon, horizontal and vertical sundials, a triquetrum, parallactic rulers, an astrolabe, a new type of armillary sphere, and a mural quadrant with an alidade. For several of these instruments, Battānī recommended sizes of more than a meter in order to increase the accuracy of the observations. In 901, Battānī observed a solar and a lunar eclipse in Antioch.

The accuracy of Battānī's observations of equinoxes and solstices, as judged from the one existing report and his determination of the lengths of the seasons, is not much inferior to that of **Tycho Brahe** 700 years later. This remarkable achievement must have been due to a careful construction and alignment of his large instruments, as well as to a clever method of combining multiple observations of the same type of phenomenon (which was certainly not simple averaging). The value obtained by Battānī for the Ptolemaic solar eccentricity, expressed sexagesimally as 2;4,45 parts out of 60, is almost exact. In fact, it is clearly better than the values found by **Nicolaus Copernicus**, who was troubled by refraction because of his high geographical latitude, and Brahe, who incorporated the much too high Ptolemaic value for the solar parallax in the evaluation of his observations.

Battānī also made accurate measurements of the obliquity of the ecliptic, which he found as 23° 35′ (the actual value in the year 880 was 23° 35′ 6″), and the geographical latitude of Raqqa (36° 1′, modern value 35° 57′). Furthermore, he determined all planetary mean motions anew. He found the parameters of the lunar model to be in agreement with Ptolemy and the eccentricity of Venus the same as derived by the astronomers working under **Ma'mūn**. (See, for example, **Yaḥyā ibn Abī Manṣūr**.) Battānī also confirmed the discovery of Ma'mūn's astronomers that the solar apogee moves by 1° in 66 Julian years, and found the precession of the equinoxes to be equal to the motion of the solar apogee. He accurately measured the apparent diameters of the Sun and the Moon and investigated the variation in these diameters, concluding that annular solar eclipses are possible. In the 18th century, Battānī's observations of eclipses were used by **Richard Dunthorne** to determine the secular acceleration of the motion of the Moon.

Battānī's most important work was a *zīj*, an astronomical handbook with tables in the tradition of Ptolemy's *Almagest* and *Handy Tables*. Ibn al-Nadīm mentions that this work (later called *al-Zīj al-Ṣābi'*) existed in two editions, "the second being better than the first," but modern attempts to date or differentiate the two versions have been unconvincing.

The *Ṣabi' Zīj* is extant in its entirety (57 chapters plus tables) in the 12th- or 13th-century manuscript Escorial árabe 908, copied in the western part of the Islamic world. Five or six insignificant fragments are scattered over several libraries in Western Europe. Between 1899 and 1907, C. A. Nallino published his monumental edition, translation, and commentary of the *Zīj* in Latin, and this remains the standard work on Islamic astronomy in general and on Battānī and *zīj*es in particular.

The *Ṣābi' Zīj* is the earliest extant *zīj* written completely in the Ptolemaic tradition with hardly any Indian or Sasanian–Iranian influences. As with many Islamic *zīj*es, its purpose was much more practical than theoretical. Although the planetary models and the determination of the solar parameters are explained in some detail (but with various errors), most of the text in the *Zīj* consists of instructions for carrying out practical calculations by means of the tables, which constitute a third of the book. With the exception of Ptolemy and some other Greek observers, Battānī does not express indebtedness to any of his predecessors. On the basis of linguistic arguments, it can be seen that he used an Arabic translation of the *Almagest* made from the Syriac. A remarkable characteristic of the text is the almost complete absence of foreign technical terminology. Although Battānī copied some of the planetary tables directly from the *Handy Tables*, he also computed many tables anew. His star table (containing approximately half the number of stars found in the *Almagest*) was obtained by increasing Ptolemy's stellar longitudes by 11° 10′, the precession in the period of 743 years between the respective epochs 137 and 880.

The *Ṣābi' Zīj* enjoyed a high reputation in the Islamic world and was very influential in medieval and Renaissance Europe. **Bīrūnī** wrote a treatise entitled *Jalā' al-adhhān fī zīj al-Battānī* (Elucidation of genius in al-Battānī's *Zīj*), which is unfortunately lost. Later *zīj*es such as those of **Kūshyār ibn Labbān**, **Nasawī**, and **Ṭabarī** were based on Battānī's mean motion parameters. In Spain, the *Ṣābi' Zīj* exerted a large influence on the earliest astronomical developments and left many traces in the *Toledan Tables*. Two Latin translations of the canons of the *Zīj* were prepared in the 12th century. The one by Robert of Chester has not survived, but the translation by Plato of Tivoli, made in Barcelona, was printed in Nuremberg in 1537 (together with **Farghānī**'s introduction to Ptolemaic astronomy) and again in Bologna in 1645 under the title *Mahometis Albatenii de scientia stellarum liber, cum aliquot additionibus Ioannis Regiomontani ex Bibliotheca Vaticana transcriptus*. The Castilian translation made from the Arabic around 1260 on the order of **Alfonso X** is partially extant with tables in the manuscript Paris, Arsenal 8.322, which was prepared for Alfonso himself. Hebrew versions or reworkings of the *Ṣābi' Zīj* were written by **Bar Ḥiyya** (12th century) and Immanuel ben Jacob Bonfils (14th century); furthermore, Battānī's influence can also be seen in the works of **Ibn ˁEzra**, **Maimonides**, and Levi ben Gerson (**Gersonides**). Finally, European scholars such as **Regiomontanus**, Copernicus, Brahe, **Johannes Kepler**, and **Galileo Galilei** made use of Battānī's work.

Besides the *Ṣābi' Zīj*, the following smaller works by Battānī are known:

1. The *Kitāb fī dalā'il al-qirānāt wa- 'l-kusūfāt* (On the astrological indications of conjunctions and eclipses) is extant in Ankara, İsmail Saib Library 199/2. This astrological treatise presents horoscopes and astrological interpretations in connection with Saturn–Jupiter conjunctions during the life of the prophet Muḥammad and the early period of Islam. It is written in the tradition of Ptolemy's *Tetrabiblos*.
2. The *Sharḥ Kitāb al-arbaˁa li-Baṭlamiyūs* (Commentary on Ptolemy's *Tetrabiblos*) is extant in the manuscripts Berlin Spr. 1840 (Ahlwardt #5875) and Escorial árabe 969/2.
3. A small work on trigonometry, *Tajrīd uṣūl tarkīb al-juyūb* (Summary of the principles for establishing sines) is extant in the

manuscript Istanbul Carullah 1499/3. Since Battānī does not use the Indian loanword *jayb* for "sine" in the *Ṣābi' Zīj*, the authenticity of this work has been questioned.

4. A *Kitāb taḥqīq aqdār al-ittiṣālāt [bi-ḥasab ʿurūḍ al-kawākib]* (On the accurate determination of the quantities of conjunctions (?) [according to the latitudes of the planets]) is mentioned by Ibn al-Nadīm and is probably identical with Chapter 54 of the *Ṣābi' Zīj*. It deals with the astrological concept of the projection of the rays, for which Battānī was the first to take into account the latitudes of the planets.
5. A *Kitāb Maṭāliʿ al-burūj fī mā bayna arbāʿ al-falak* (On the ascensions of the zodiacal signs between [the cardinal points of] the quadrants of the sphere) is also mentioned by Ibn al-Nadīm and is probably identical with Chapter 55 of the *Zīj*. It provides methods of calculation needed in the astrological problem of finding the *tasyīr* (*aphesis* or *directio*).

According to Ibn al-Nadīm, Battānī lived for some time in Baghdad towards the end of his life, because of financial difficulties brought about by dealings with the family of the Banū al-Zayyāt (presumably descendents of the famous poet and vizier ʿAbd al-Malik ibn Abān al-Zayyāt) in Raqqa. On his way back to Raqqa, Battānī died at the castle Qaṣr al-Jaṣṣ near Samarra, 100 km north of Baghdad.

Benno van Dalen

Alternate name

Albategnius [Albatenius]

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Baxendell, Joseph

Born **Smedley near Manchester, England, 19 April 1815**
Died **Birkdale (Mersey), England, 7 October 1887**

Joseph Baxendell, an astronomer and meteorologist, is noted for his pioneering work on solar–terrestrial relationships, and studies of variable stars, of which he discovered 18. His work typifies that of the devotee so prominent before the professionalization of science.

Baxendell was the eldest of the eight children (six sons and two daughters) born to Thomas Baxendell, a self-made man who farmed at Smedley. His mother (*née* Mary Shepley), is said to have had a strong love of astronomy, and it is possible that Joseph's interest in science dates back to her influence. This inclination was further encouraged by Thomas Walley. Joseph received his early education at his school at Cheetham Hill, Manchester. Here he proved himself a rapid learner, and demonstrated his aptitude for mathematics. Baxendell does not appear to have devoted much time to experimental enquiry, but did so in his observational abilities and inclination towards mathematics. He gave early indications of the direction of his later development. Having quickly acquired all his teacher could impart, Baxendell left school at age 14; hence, in the words of his biographer, James Bottomley, he can be said to have been largely self-taught.

A weak constitution in childhood necessitated frequent trips to Southport, a nearby seaside resort, and led to a lifelong enthusiasm for all things maritime. At the age of about 14, in the hope that a sea voyage would invigorate his health, Baxendell embarked on the *Mary Scott*, bound for Valparaiso, Chile. Over the next 6 years, he made several voyages, and in 1833 off the Pacific coast of Central America, Baxendell made good use of his powers of observation when he had the good fortune to witness the extraordinary Leonid meteor shower of 13 November. Two years later, he experienced the shock of the earthquake that devastated the Pacific coast of South America. That same year, he abandoned the sea, though not through disgust with seafaring life; Baxendell returned to Manchester, where he assisted his father before setting up in business as an estate agent. He also worked in a quiet unobtrusive way on his studies of astronomy and meteorology.

At first, Baxendell settled in Stocks Street, Cheetham, but moved to Crescent Road, Cheetham Hill, not far from where his friend Robert Worthington of Crumpsall Old Hall had set up an observatory. This housed a large 13-in. reflector, the speculum of which Baxendell had cast, ground, and polished, as well as a 5-in. equatorial refractor. As an accident to his right eye debarred Worthington from its use, Baxendell utilized the facility until its removal in 1869. The excellent work done at the Crumpsall Observatory, which included observations of variable stars, meteors, comets, planets, sunspots, and eclipses, won it a high place among private observatories, and put Baxendell in contact with leading astronomers across the globe. Among these was **Norman Pogson**, Government Astronomer at Madras, whose sister Baxendell married in 1865. They had one son, Joseph.

The year 1858 seems to have been a watershed. In January, Baxendell joined the Manchester Literary and Philosophical Society [MLPS], and later that year was enrolled as a yellow of the Royal Astronomical Society. The following year he became a Council member of the former society, and was appointed Manchester's municipal astronomer in succession to the Reverend Henry Halford Jones. Two years later, in 1861, Baxendell became joint secretary of the MLPS as well as assuming responsibility for publication of the society's *Memoirs and Proceedings*. He held the former position until 1885, the latter until his death. Baxendell's colleagues in the secretaryship were Sir H. E. Roscoe (until 1873), and professor Osborne Reynolds. In 1884, Baxendell was elected as fellow of the Royal Society, by which time he had published over 70 papers and several catalogs of variable stars. Although most of his work appeared in the *Proceedings of the Manchester Literary and Philosophical Society*, he also published in the *Proceedings of the Royal Society*, and contributed to the *Astronomische Nachrichten*, the *Observatory*, the *Journal of the Liverpool Astronomical Society*, and the *Monthly Notices of the Royal Astronomical Society*. Baxendell's earliest work on variable stars appeared in the latter publication and was entitled "On the Variability of λ Tauri."

Apart from his studies of variable stars, Baxendell is best remembered for what professor **Balfour Stewart** eulogized as his pioneering contributions to meteorology. In his paper "On Solar Radiation," Baxendell deduced that the maxima and minima of heat energy given off by the Sun correspond with sunspot frequency, while in one of his most original and important papers ("On a Periodic Change …"), he thought it highly probable that changes in the output of solar energy were more complicated than previously assumed. To explain a short variable period that he had detected, Baxendell conjectured the existence of a ring of nebulous matter circling the Sun in a plane nearly coincident with the plane of the ecliptic. This, he supposed, acted not only to reflect and absorb part of the radiation that would otherwise have reached the Earth, but altered the direction of the lines of magnetic force, that influence being more marked than the thermal influence.

Subsequent to his appointment as Manchester's municipal astronomer, Baxendell supervised the construction of the Fernley meteorological observatory in Hesketh Park, Southport. He also became meteorologist to the corporation of that town. His service to the community in this capacity was highly effective. Baxendell took an intense interest in the issue of storm warnings, and objected vigorously when the Board of Trade proposed their abolition. His warnings of the summer drought of 1868 enabled the Manchester Corporation Water Works to implement effective precautions. Baxendell was also correct, it seems, in alerting the authorities in Southport to an outbreak of smallpox epidemic.

Towards the end of his life, Baxendell showed great interest in the manner in which the Great Pyramid of Egypt had been constructed. At his last residence in Birkdale, near Southport, he erected a small observatory; with the help of his son, who succeeded him as meteorologist to the corporation of Southport, he resumed his astronomical work.

Baxendell lived a quiet, retired life. He is said to have been of an amiable disposition, and had a firmness of character. In his later years, he experienced difficulty in breathing and was afflicted by a painful disease of the lower jaw.

Richard Baum

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Bayer, Johann

Born **Rain, (Bavaria, Germany), 1572**
Died **Augsburg, (Bavaria, Germany), 1625**

Johann Bayer is known mainly for his celestial atlas entitled *Uranometria* (Augsburg, 1603), and for having introduced the star nomenclature that is still in use.

Astronomer and lawyer, Bayer studied in Ingolstadt and Augsburg and became legal adviser to the city council of Augsburg. Although collections of celestial maps were published in Italy during the 16th century, as part of astronomical treatises by **Alessandro Piccolomini** and **Giovanni Gallucci**, *Uranometria* presented for the first time all the characteristics typical of the great celestial atlases of the modern age: the large format, the maps of constellations with the corresponding mythological figures, and the catalog of the stars contained in the celestial charts. (Bayer drew his data from the catalog of **Tycho Brahe.**)

While Piccolomini identified the stars by means of Latin letters, Bayer introduced a nomenclature based on the use of Greek letters followed by the genitive of the constellation name. So, for example, Aldebaran and Deneb were identified by Bayer as α Tauri and α Cygni, respectively.

Another important novelty of *Uranometria* resides in the first printed representation of the southern sky according to the new constellations introduced by the Dutch navigators **Pieter Keyser** and Friedrich de Houtman. They proposed to add 12 asterisms to the 48 Ptolemaic constellations, in order to cover the region of the sky around the South Pole, which had remained unknown to European astronomers until the age of great geographic discoveries.

After *Uranometria*, Bayer continued his activity in celestial cartography and, in the last years of his life, offered his collaboration to the preparation of a new atlas, entitled *Coelum Stellatum Christianum*, published by **Julius Schiller** in 1627.

Davide Neri

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Beals, Carlyle Smith

Born **Canso, Nova Scotia, Canada, 29 June 1899**
Died **Ottawa, Ontario, Canada, 2 July 1979**

Canadian astrophysicist Carlyle Beals is most widely remembered for relatively late work on identifying impact (meteorite) craters in northern Canada and using their properties in analysis of lunar cratering, but he also discovered that the interstellar medium consists partly of discrete clumps or clouds. Beals was the son of the Reverend Francis H. P. Beals and Annie Florence Nightingale Smith. He married Miriam White Bancroft in 1931, and they had one daughter, Janitza. His sister married **Roderick Redman**.

Beals attended local schools and then Acadia University, taking a B.A. in mathematics and physics in 1919. After a period of rural teaching, he entered the University of Toronto, obtaining an M.A. in 1923. Following further teaching, Beals moved to Imperial College, London, where, as a student of **Alfred Fowler**, he specialized in spectroscopy. He took a diploma in 1925 and a Ph.D. in 1926. After a year as an instructor at Acadia University (1926–1927), Beals joined the staff of the Dominion Astrophysical Observatory, where he became assistant director in 1940. London University awarded him the D.Sc. in 1934.

In 1946, Beals moved to Ottawa to become Dominion Astronomer and director of the Dominion Observatory. He was the first astrophysicist to head the observatory, and brought in sweeping changes. Under his direction, staff publication increased significantly and new fields were developed, such as geophysics, meteor studies, radio astronomy – with the creation of the Dominion Radio Astrophysical Observatory in 1960 – and Beals' own research into meteorite impact features. He retired in 1964, but continued consulting work in lunar and planetary sciences.

Beals was particularly interested in analysis of the spectra of hot stars displaying emission lines. He laid down a basic classification scheme for the Wolf–Rayet [WR] stars, with separate sequences for spectra dominated by carbon and nitrogen lines. Beals' explanation of the complex shapes of lines in the P Cygni stars (that an expanding cloud around the star imposed blueshifted absorption lines as well as adding redshifted and undisplaced emission lines) proved to be correct, and he also attempted to determine the outflow structure of material expelled by nova explosions, though less successfully. His attempt to determine the temperatures of WR stars by a method analogous to that of **Hermann Zanstra**, for the central stars of planetary nebulae, revealed that WR atmospheres are not really in a state of local thermodynamic equilibrium.

In 1939, examining a spectrogram of the bright, hot star R Leonis, Beals recognized that the sharp (hence interstellar) absorption feature of ionized calcium had several partially separated components at different velocities, implying that it was produced by several discrete gas clouds rather than a continuous distribution. He and younger Canadian–American astronomer J. Beverly Oke later calibrated the strength of the calcium feature as a distance indicator for stars within the galactic plane. More extensive work on multiple components was done by **Walter Adams** and **Alfred Joy**.

Upon arriving in Ottawa, Beals began examining Royal Canadian Air Force photographs of the northern regions of Canada. He picked out a number of craters which later geological investigation identified as being the products of impacts rather than of (commoner) volcanoes, and later applied that expertise to the analysis of images of lunar craters (most of which are impact products).

Beals was a fellow of the Royal Society of London, an officer in the Order of Canada, a fellow of the Royal Society of Canada (and a recipient of its Tory Medal), president of the Royal Astronomical Society of Canada (1952), and president of the American Astronomical Society (1962–1964), the only Canadian so to serve. The Meteoritical Society awarded him its first Leonard Medal in 1966. He had honorary degrees from Acadia, New Brunswick, Queen's, and Pittsburgh universities.

Richard A. Jarrell

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Becquerel, Alexandre-Edmond

Born **Paris, France, 24 March 1820**
Died **Paris, France, 11 May 1891**

Edmond Becquerel was both son and father of famous French physicists. Edmond photographed the solar spectrum into the ultraviolet. He is better known for the discovery of the photoelectric effect, later explained by **Albert Einstein**.

Selected Reference

Zworykin, V. K. and E. G. Ramberg (1949). *Photoelectricity and Its Application*. New York: J. Wiley.

Bečvář, Antonín

Born **Stará Boleslav, Bohemia, (Czech Republic), 10 June 1901**
Died **Brandýs nad Labem, (Czech Republic), 10 January 1965**

Though Antonín Bečvář suffered all through his life from a skeletal irregularity, he made important contributions to astronomy through both his observational programs and the very detailed atlases and catalogs that he developed to support those programs. Bečvář began systematic observations of the night sky from a modest observatory he built in 1927 in his family's garden. Although he started his studies at Charles University in Prague, those studies were interrupted, and he did not graduate until 1934. He received a Ph.D. degree in meteorology from the Institute of Meteorology where he also found his first employment.

Bečvář's personal illness led him to Slovakia's High Tatras Mountains, where he would later spend most of his astronomical career. Bečvář became fascinated with the weather and climate of the Tatras, especially with the many different kinds of clouds that formed in and around the mountains. He would later become an authority on clouds, writing a well-illustrated book on the subject in 1953. In 1937, Bečvář accepted a position as climatologist at the Štrbské Pleso Spa in the Tatras. At Štrbské Pleso, Bečvář realized from the daily meteorological data he collected that the Tatras region offered optimal conditions for astronomy. Bečvář built his own telescope and used it primarily for solar observing. He also designed and constructed a battery of wide-field cameras that he used to photograph comets and meteors.

In 1941, Bečvář founded the Skalnaté Pleso (Rocky Lake) Observatory, serving as its first director from 1943 to 1950. At an altitude of 1,783 m, it was one of the highest in Europe.

Skalnaté Pleso Observatory's inaccessibility saved it from destruction during World War II. In January 1945, Bečvář's extended negotiations saved the telescopes and other astronomical equipment from removal by German forces. Later the same month, retreating Fascist troops tried to ascend the Tatras mountain peak with the intent of blowing up the observatory, but were thwarted by workers who operated the funicular that provided the only transport to the top. Instead, they only blew up the bottom station of the funicular.

Despite frequently fierce winds, observers at Skalnaté Pleso enjoyed an excellent climate for astronomical research. In 1946, Skalnaté Pleso observers recorded meteors on 27 consecutive cloudless nights and were able to get accurate sunspot counts for 250 days in a row. Bečvář equipped the observatory with reflecting telescopes of 24-cm and 60-cm apertures. Under his leadership, Skalnaté Pleso became known for its solar astronomy, discoveries of comets, and photography of meteors using an improved version of the wide-field cameras, first used by Bečvář at Štrbské Pleso. Bečvář became an expert observer of meteors, especially the Ursid shower, and of comets, discovering comets C/1942 C1 (Whipple–Bernasconi–Kulin) and C/1947 F2 (Bečvář). Sixteen other comets were discovered at Skalnaté Pleso in the first two decades of the observatory's existence – an amazing achievement in the decades before Charge-Coupled Device [CCD] detectors became available.

Today, Bečvář is best known for his beautiful and information-packed celestial atlases, the creation of which was motivated by Skalnaté Pleso's searches for comets. Bečvář realized that no prior star atlas had adequately plotted nonstellar objects. In 1948, Bečvář completed his *Atlas Coeli* (*1950*), charting 35,000 objects at a scale of 1° = 0.75 cm. The *Atlas Coeli* (commonly referred to by English speaking observers as the *Skalnaté Pleso Atlas*) includes stars to the visual magnitude limit of 7.75; visual double stars and spectroscopic binary stars; novae and supernovae; Milky Way isophotes; and many globular and open star clusters, diffuse and dark nebulae, and galaxies. This atlas was notable as the first to include the many sources of extraterrestrial radio waves discovered after World War II. Bečvář used the *General Catalogue of 33,342 Stars* (1937) by **Benjamin Boss** as the basis for the stellar data in *Atlas Coeli*, supplemented by data from Harvard's *Henry Draper Catalogue* (1918–1924) for the fainter stars.

In 1950, Bečvář published his own comprehensive catalog of 12,000 selected objects that appeared in *Atlas Coeli*. From 1958 to 1964, he produced three large-scale (1° = 20 cm) spectroscopic atlases covering the declination zones +90° to +30°, +30° to −30°, and −30° to −90°. Titled *Atlas Borealis*, *Atlas Eclipticalis*, and *Atlas Australis* respectively, these charts depicted stars to a limiting magnitude of about 9.0 with six different colors to reflect their spectral types. The *Yale Zone Catalogues* provided the stellar data for these three atlases.

In 1951, Bečvář was suddenly released from his position as director. He returned to his family home in Brandýs nad Labem and continued his meteorological and astronomical studies. However, most of his effort was devoted to improving editions of his atlases and catalog. He never married; the last years of his life were spent with his sister in their family house. Bečvář was a devoted photographer and a sensitive piano player. For his contributions to celestial cartography, Bečvář was honored by having a crater on the Moon's farside and asteroid (4567) Bečvář named for him.

Peter Wlasuk and *Martin Solc*

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Bede

Born **England, *circa* 673**
Died **735**

Bede's main and best-known work in astronomy concerns the problem regarding the calendar and his construction of a table for determining Easter.

Bede was born in or about 673 in the coastal region of the northeast of England lying between the estuaries of the rivers Tyne and Wear (possibly in Jarrow), which was in the Anglo–Saxon Kingdom of Northumberland. At the age of seven, he was admitted to the newly built abbey of Wearmouth nearby and, soon after, transferred to the even newer abbey at Jarrow, these twin monasteries having been founded by Bishop Benedict. (Saint Paul's Church in Jarrow, where Bede spent most of his life, was, unusually for the time, built from stone and still stands complete, as do the remains of the monastery.) He was made deacon at the age of 19 and a priest when 30, and was also choirmaster in the monastery. Bede probably never travelled outside this region during his entire life.

Bede was a man of extraordinary learning and, although much of his literary output was religious, he contributed significantly to astronomy and also to history. Although he is best known for his *Historia Ecclesiastica*, written in 725 (a detailed history of Britain and her church, much quoted by Anglo–Saxon historians), he also wrote three other books that are particularly important for science and astronomy. These are *De Natura Rerum* (701), *Liber de Temporibus* (703), and *De Temporum Ratione* (725), of which the last is the most significant, being an updated and expanded version of *Liber de Temporibus*. Bede made full use of the excellent library that Benedict had accumulated during his European travels and set up in Jarrow. He was also much influenced by, and drew heavily upon the works of, **Augustine**, **Pliny,** and **Isidore**.

The date-of-Easter problem had attracted attention for many centuries, but was confused by a multiplicity of different calculational techniques, varying equinox dates, religious ideology, and by its link with the Jewish Passover. Since the Jewish calendar (and many others) was lunar, and since Passover and Easter are closely linked, the main idea was to unify the solar year with the lunar month and to try and find a period of time that was, as nearly as possible, equal to a whole number of years, and at the same time, equal to a whole number of lunar months. Many systems were tried, including the 8-year (99 months) "octaeteris" cycle and the 84-year (1,039 months) cycle. But the most accurate cycle came from an Athenian of the 5th century BCE, **Meton**; it consisted of a 19-year (235 months) cycle. Bede, developing an earlier idea, chose a period of 532 years. This is 28 successive cycles of the 19-year cycle, Bede recognizing that, since there is a leap year every 4 years, and 7 days in the week, and since 4, 7, and 19 are coprime, a cycle of length equal to the product of 4, 7, and 19 (equals 532) years would be the shortest period based on the 19-year cycle that would "repeat" itself exactly. In *De Temporum Ratione*, Bede drew up a table from 532 until 1063 that, among other things, gave the Easter (full) Moon and Easter Sunday for each of these 532 years. (In the *Historia Ecclesiastica*, Bede gives an interesting discussion of the dispute between the Roman and Celtic Churches in Britain and Ireland regarding the date of Easter, which was settled at the Synod of Whitby in 664 with victory to the Roman Church.)

Bede taught extensively at Jarrow, and it is encouraging to note that he distanced himself completely from astrology. From his teachings and writings, he had a clear concept of the relationship between latitude and hours of daylight, and explained how this arose from the inclination of the "orbit" of the Sun (around the Earth) to the celestial equator. Bede also experimented with sundials and shadows, described both solar and lunar eclipses and even postulated on the structure of stars. He gave a careful discussion of the phases of the Moon and of the relationship between the Moon and tides (the latter being probably the best until **Isaac Newton**'s work nearly a thousand years later). Bede also showed that the vernal equinox was not on 25 March, as taken by the Julian calendar, and is credited with the introduction of the "AD" dating terminology, following a suggestion by **Dionysius Exiguus**.

Graham Hall

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Beer, Wilhelm

Born **Berlin, (Germany), 4 January 1797**
Died **Berlin, (Germany), 27 March 1850**

Wilhelm Beer, a banker and amateur astronomer, is noted mainly for his contributions to the mapping of Mars and the Moon. Beer was the head of a family banking firm in Berlin, and half-brother of the composer Giacomo Meyerbeer. **Alexander von Humboldt** introduced Wilhelm Beer to the astronomer **Johann von Mädler**, who became his friend and mentor. Beer established a small observatory with a 12-ft. dome at his villa in the Tiergarten of Berlin, where he installed a 3.75-in. Fraunhofer refracting telescope that he had purchased from another amateur astronomer, Johann W. Pastorff. With the telescope, Beer and Mädler made an excellent series of observations of Mars at its opposition of 1830 that led to the first map of its surface, and laid the foundation for modern study of the planet.

The names of Beer and Mädler are inseparably linked as joint authors of the epoch-making *Mappa Selenographica* (1834–1836), a chart in four sections of the visible hemisphere of the Moon begun in 1830, and of its accompanying book *Der Mond* (1837). Though joint authorship is specified, it is known that most of the actual observation and mapping of the lunar surface was done by Mädler. In turn, Mädler related his system of 105 micrometrically measured reference points to the previous measurements of **Wilhelm Lohrmann**. Beer was the patron who provided Mädler with facilities to pursue his interest. Beer and Mädler also produced a book on the Solar System that contains their observations of Mars. After Mädler's departure to take charge of the Czar's observatory at Dorpat in 1840, Beer did no further astronomical work of significance.

Richard Baum

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Behaim, Martin

Born **Nuremberg, (Bavaria, Germany), 6 October 1459**
Died **Lisbon, Portugal, 29 July 1507**

Martin Behaim originated the oldest extant globe of the Earth (1492). Son of Martin Behaim the Elder and Agnes Schopper, he was the offspring of an influential noble family that was involved in long-distance trade in the city republic of Nuremberg. After the death of his father in 1474, Martin's uncle Leonhard sent him at the age of 15 to Flanders (Mecheln, Antwerp) for professional training as a textile merchant.

After 1484, Behaim lived in Portugal; the reasons that led him to this foreign country are unknown but probably related to the spice business. Quickly playing an important role as a counselor at the court of King John (Joao) II, he certainly got in touch with prominent cartographers and navigators. In fact, there has been much speculation about Behaim's life in Portugal, and many legends arose for which there is no evidence from archival sources. It can no longer be claimed that he taught celestial navigation to the Portuguese, because the scientific elements that made celestial navigation possible were already present on the Iberian Peninsula before his arrival. But he may have acted as an importer of scientific instruments, the finest of which were produced at that time in his native town of Nuremberg.

In 1490, Behaim visited the city of his fathers to settle a will case, and he stayed in Nuremberg for 3 years. He managed to convince leading members of the city council to finance the manufacturing of the famous globe of the Earth under his direction. The decisive reasons still are unknown, but many inscriptions on the globe indicate an economic motivation. Whereas the final financial account of 1494 indicates clearly which craftsmen were involved in its making, the Behaim globe must be regarded as a joint achievement of the Nuremberg humanist circle. It is an early masterpiece of many kinds of scientific and technological achievements, establishing the intellectual and economic leadership of Nuremberg in late medieval Germany.

Behaim died in the hospice of Saint Bartholomew while on one of his trips to Lisbon.

In fact, nothing can be said about whether Behaim contributed to astronomy at all. Certainly, he was not a student of **Johann Müller** (Regiomontanus), as has often been claimed. Regiomontanus's house was next to the Behaim house at the central market place in Nuremberg, However, when Regiomontanus lived there, Martin Behaim was a boy of 12–15 years, and there is no indication that Regiomontanus gave lessons to Behaim.

Furthermore, one can no longer defend the thesis that celestial navigation was possible only because of Behaim's teaching the Portugese how to use the cross staff (Jacob's staff or ballestilla) and the astronomical tables of Regiomontanus. The cross staff, invented by Levi ben Gerson **(Gersonides)**, already was well-known on the Iberian Peninsula. Moreover, the declination of the Sun given in the *Tabula Directionum* of Regiomontanus is different from that found in the *Regimento do astrolabio … Tractado da spera do mundo* prepared by the Portuguese Council of Mathematicians for use by navigators. The same holds for the use of the astrolabe on ships.

Behaim's great merit lies in his origination of the oldest extant terrestrial globe – although probably not the first at al – which must be regarded as a complex cosmographical model. Nevertheless, his life and his globe give clear evidence that he was not a great navigator, mathematician, and astronomer, as many publications still celebrate him.

The globe is luxuriously decorated. It contains more than 2,000 place names, 100 pictorial illustrations (plus 48 banners and 15 coats of arms), and more than 50 long legends. Many of them deal with peculiarities and fabulous monsters of foreign countries, their inhabitants, plants and animals, and (in particular) with overseas trade, explorations, and famous travels like that of Marco Polo. Not the quality of the information, but its quantity and selection make the globe an important primary source for historical research. Obviously, Behaim had no main source for his *Erdapfel*. He gathered the geographical information from different sources, probably from a nowadays missing Portuguese sea chart, travel narratives like that of Marco Polo, Mandeville, and the Portuguese explorer Diego Gomes, and of course traditional cosmographical writings like **Ptolemy's** *Geography*. For that reason, the Behaim Globe is one of the very few existing cartographical works where different "schools" of mapmaking are bound together.

Guenther Görz

Alternate name

Martin of Bohemia

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Belopolsky, Aristarkh Apollonovich

Born **Moscow, Russia, 13 July 1854**
Died **Pulkovo, (Russia), 16 May 1934**

Aristarkh Belopolsky was a pioneer in the application of spectroscopy, and especially radial velocity measurements, to the study of the stars. Belopolsky's father was a well-educated teacher whose ancestors had immigrated to Russia from the Serbian town of Belopolje, from which the family's name was derived. After an excellent secondary education, Belopolsky studied at Moscow University and graduated in 1877. During his studies, he came under the tutelage of **Fedor Bredikhin**, director of the Moscow Observatory. On account of Belopolsky's mental vigor and technical skills, Bredikhin appointed him as an assistant at the observatory and encouraged him to participate in its solar observations. In 1886, Belopolsky completed his Magister's thesis on the motions of sunspots. He then obtained several photographs of the corona during the total solar eclipse of 19 August 1887 near Pogoste (approximately 100 miles northeast of Moscow).

Belopolsky's talents eventually attracted the attention of **Otto Wilhelm Struve**, who invited him to join the staff of the Pulkovo Observatory in 1888. Three years later, Bredikhin succeeded Struve as Pulkovo's director and placed his former student in charge of all astrophysical equipment. Belopolsky was directed to purchase a standard *Carte du Ciel* astrograph and several stellar spectrographs. In 1891, he journeyed to Potsdam, where, along with American astronomer **Edwin Frost**, he learned the techniques of radial velocity measurements from spectroscopist **Hermann Vogel**.

Armed with new spectroscopic equipment and fresh ideas, Belopolsky set to work on the new field of observational astrophysics. Independently of **James Keeler**, he demonstrated the differential rotation of Saturn's rings (1895). In 1894, he discovered periodic changes in the radial velocity of δ Cephei, and noted the phase shift between its brightness variations and the Doppler oscillations. Continued studies of this star netted Belopolsky his Ph.D. in 1896, from which the first hypotheses of stellar radial pulsations originated. Belopolsky likewise reported analogous behavior for η Aquilae (1896) and ζ Geminorum (1899). In 1906, he announced the long-period oscillation in the radial velocities of Algol (β Persei), thereby confirming the eclipsing binary hypothesis of **John Goodricke** and **Edward Pigott**.

Equally important were Belopolsky's contributions to the study of novae. Beginning with the appearance of Nova Aurigae (1892) through Nova Aquilae (1918), he observed each one, often catching them in their earliest pure-absorption stage. It was perhaps consideration of the expansion of novae that led him to think of expansion as an important phenomenon in general, an attitude that appears to have influenced **Victor Ambartsumian**.

Belopolsky maintained an interest in solar studies throughout the remainder of his career, measuring the effective temperature of sunspots, timing the Sun's rotation from the motion of faculae, and securing a large solar spectrograph of the Littrow type from Sir **Howard Grubb**.

In 1902, Belopolsky was appointed to the editorial board of the *Astrophysical Journal*, and the following year was elected a member of the Russian Academy of Sciences. He became an associate member of the Royal Astronomical Society in 1910. From 1917 to 1919, he served as director of the Pulkovo Observatory, but then resigned his position due to the impact of administrative duties on his research activities.

Of Belopolsky, his colleague **Boris Gerasimovich** wrote: "His most striking qualities were modesty, moral courage, clear vision and enormous devotion to science and industry. In the terrible years of the civil war, this old man, cold and hungry, continued his work as usual – an example of true heroism."

Belopolsky was named honorary director of the Pulkovo Observatory in 1931 and continued his research on stellar spectra until his death.

Thomas J. Bogdan

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Ben Solomon: Judah ben Solomon ha-Kohen

Born **Toledo, (Spain), *circa* 1215**
Died **probably (Italy), after 1274**

Judah ben Solomon was born and educated in Toledo, where the Jewish community, despite a century and a half of Christian rule, maintained a tradition of Arabic learning in science and philosophy. At the age of 18, he entered into correspondence with some savants at the court of Frederick II. Apparently as a result of these exchanges, Judah immigrated to Italy. There he translated into Hebrew his major work, an encyclopedia called *Midrash ha-ḥokhmah* (The study of wisdom), which he had earlier compiled in Arabic.

The astronomical section of *Midrash ha-ḥokhmah* is a combination of the theories of **Ptolemy** and **Biṭrūjī**. For matters of timekeeping, mathematical geography, and solar and lunar theory, Judah relies upon Ptolemy. However, when moving on to planetary theory, he abandons Ptolemy in favor of Biṭrūjī. Judah preferred Biṭrūjī for theological reasons. In the latter's system, in which the motions of the planetary orbs were all powered by a mechanical link to the swiftly moving outermost orb, the connection between God and the Universe was patently clear: God set in motion the outermost orb, with the daily revolution, and this energized the entire cosmos.

Biṭrūjī was not the only Andalusian astronomer whose work influenced *Midrash ha-ḥokhmah*. **Jābir ibn Aflaḥ**, **Ṣāˁid al-Andalusī**, and an otherwise unknown Jewish astronomer by the name of David ben Naḥmias are also cited. Judah knew as well the discussion of the "moon illusion" in **Ibn al-Haytham**'s commentary to the *Almagest*.

To the extent that there are original investigations in *Midrash ha-ḥokhmah*, they are motivated by theology or mysticism. Thus, for example, Judah noticed that Ptolemy's value for the ratio in volume between the Sun and the Moon, 6644.5, is an approximation (*Almagest* V.16; *cf. ibid*., V.14). The exact value, which Judah asserts to be 6,300, is obtained not by observation, but by an operation upon the alphanumerical values of the two letters of the Hebrew alphabet that are said to stand for the Sun and the Moon.

Y. Tzvi Langermann

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Bennot, Maude Verona

Born **Thornton, Illinois, USA, 5 June 1892**
Died **Rochester, Minnesota, USA, 9 September 1982**

Planetarian Maude Bennot, daughter of Charles and Amelia (*née* Dickel) Bennot, graduated as valedictorian of her class from Thornton Township High School in Harvey, Illinois. She was accepted into Northwestern University in 1912, but did not complete her bachelor's degree until 1919, with intervening stints of employment at the National Research Council, the War Labor Board, and coursework taken at George Washington University. Between 1921 and 1924, Bennot served as an editor at the Mayo Clinic, Rochester, Minnesota, and then returned to Northwestern University to pursue graduate studies in astronomy. Working with Dearborn Observatory director **Philip Fox**, in 1927 Bennot completed requirements for a master's degree in astronomy, writing a thesis on the proper motions of forty stars. Her results were published in the *Astronomical Journal.*

Fox was chosen to direct Chicago's Adler Planetarium in 1929. He quickly secured Bennot's appointment as assistant director. Together they designed the planetarium's schedule of monthly programs as an introductory course in astronomy. Bennot traveled to Europe in 1933 to examine Zeiss planetaria operations at Jena, Berlin, Hamburg, Stockholm, Milan, and Rome. When Fox left the Adler Planetarium in 1937 to direct Chicago's Museum of Science and Industry, Bennot was appointed the Adler Planetarium's acting director, a position she held until 1945. She thus became the first woman to head a planetarium facility in the United States, and probably the world. Since no additional staff was provided, Bennot's responsibilities were in fact doubled to include both the director's and assistant director's duties. Continued economic depression and the coming of war brought cuts in budget, personnel, and attendance, leaving Bennot as the one-person planetarium staff by 1944. Yet her wartime workload was actually increased as a consequence of teaching celestial navigation to naval midshipmen. But in spite of thrifty management policies, popularity with the public, and fifteen years of devoted service, Bennot was suddenly removed from her position in 1945, following the death of her mentor, Fox, from a cerebral thrombosis the previous year.

The decision to replace Bennot with a man – Wagner Schlesinger, the son of astronomer **Frank Schlesinger**, was appointed director of the Adler Planetarium – was engineered by Robert J. Dunham, Chicago Park District board president, and undertaken with full approval of planetarium donor Max Adler. Under Dunham's plan, Bennot would receive only three months salary in 1945. Afterwards, the assistant director's position would be eliminated, preventing Bennot from reacquiring even her original means of employment. Bennot charged that this action constituted a subterfuge and deliberate evasion of the civil service laws. She was represented by Marvin J. Bas, an attorney for the civil service employee's association, who termed the board's failure to offer her a full year's salary a willful circumvention of the merit system. Bas, however, was unable to reverse the board's predetermined objective. Bennot left the field of astronomy education forever. Her subsequent career remains unknown.

During the 1930s, Bennot was elected treasurer and second vice president of Sigma Delta Epsilon, the national graduate women's scientific association. She served faithfully as secretary of the Chicago Astronomical Society from 1938 to 1944. In 1943, Bennot was appointed by the Midwest Committee of the Polish Institute of Arts and Sciences to serve as commentator at the observance of the 400th anniversary of the publication of Copernicus's *De Revolutionibus*. She was, by any measure, a woman of substantial ability who deserved better treatment than she received from Chicago Park District authorities after Philip Fox was no longer able to shield her from their prejudices.

Ironically, in 1932 Bennot observed a total solar eclipse from an aircraft, which sparked her interest in aviation. She later admitted, "Amelia Earhart's was the only job I might have preferred to my own." Had she then known the outcome of her career in astronomy, she might well have decided to pursue that alternate goal more seriously.

Jordan D. Marché, II

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Benzenberg, Johann Friedrich

Born **Schöller near Elberfeld, (Nordrhein-Westfalen, Germany), 5 May 1777**
Died **Bilk near Düsseldorf, (Germany), 7 June 1846**

Johann Benzenberg, the codiscoverer of the upper-atmospheric (nontropospheric) location of meteors, later funded a private observatory at Bilk, which became an important center of minor-planet research. He was the son of Heinrich Benzenberg, a Protestant theologian (1744–1809), and Johanna Elisabeth (*née* Fues). In 1807, he married Charlotte Platzhoff (1789–1809) of Elberfeld. After studying theology (at Herborn and Marburg), Benzenberg went to Göttingen, where he developed a strong interest in science by attending the lectures of Georg Christoph Lichtenberg and Abraham Gotthelf Kästner. Following Lichtenberg's death, Benzenberg received his Ph.D. from the University of Duisburg in 1800. In 1805, he became a professor of mathematics at the Lyzeum (women's college) of Düsseldorf and the director of surveying for the Duchy of Berg. After immigrating to Switzerland during the Napoleonic occupation of his country, Benzenberg returned to concentrate on a political career, with particular interests in constitutional law and economics. His proficiency in experimental physics led to engineering work, including a strong involvement in local railway projects.

In 1844, Benzenberg built a private observatory at Bilk, which he donated to the city of Düsseldorf with a grant to pay for the salary of a resident astronomer. This position was subsequently filled by **Johann Schmidt**, **Franz Brünnow**, and **Karl Luther**, under whose directorship Bilk became one of the more important centers of minor-planet observations in Europe.

Benzenberg's practical skills made him an ideal collaborator with **Heinrich Brandes** in their observing campaign to determine the atmospheric altitude of meteors at Göttingen. Later, Benzenberg successfully demonstrated the Earth's rotation by conducting "falling body" experiments originally suggested by **Isaac Newton**. The first was conducted in 1802 from a church staple at Hamburg; this was repeated in 1804 within a mine shaft in the countryside. His textbooks on applied geometry and surveying were intended to establish solid procedures for the systematic mapping tasks on the public agenda at that time.

Benzenberg's sometimes original and imaginative approach to scientific matters resulted in his proposal to use simultaneous meteor observations for the determination of geographical longitude differences (an idea that had been put forward for fireballs by **Edmond Halley**). It also caused him to retain throughout his life the early notion of meteors being *ejecta* from lunar volcanoes, despite the strong contrary evidence that accumulated in the meantime.

Wolfgang Kokott

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Bergstrand, Östen

Born **Sweden, 1 September 1873**
Died **Sweden, 27 September 1948**

Östen Bergstrand's greatest contribution to astronomy was the fostering of the ideals of precision astrometry and astrophysics in Sweden, which he handed on to a younger generation of better-known astronomers. He was the son of Carl Erik Bergstrand and Jenny Rosalie Wallin, and married, first, Anna Elfrida Ericsson (1901) and, second, Ingrid Svensson (1942). Bergstrand received his Ph.D. in astronomy at Uppsala University in 1899, working under **Nils Dunér**, who modernized the instrumentation at Uppsala, obtaining a double refractor useful for both classical astronomy (astrometry) and astrophysics. Bergstrand worked in both of these fields.

Bergstrand was appointed assistant professor (docent) at Uppsala Observatory in 1901 and professor from 1911 to his retirement in 1938. He was elected to the Royal Swedish Academy of Sciences in 1924 and as a vice president of the International Astronomical Union in 1935. He studied the theoretical aspects of photographic determination of stellar parallaxes, as well as measuring a number of parallaxes himself. Bergstrand also participated in the international campaign to measure the positions of the minor planet (433) Eros, with the aim of improving the precision in the value of the solar parallax.

Together with astronomers such as **Ejnar Hertzsprung**, Bergstrand developed the method of effective wavelengths for determining the temperatures of stars. Very low resolution spectral plates are obtained by placing a coarse grating in front of an astrograph. The distance on the plate between the zeroth and almost point-like first-order spectra is proportional to the wavelength where most of the star's energy falls, and so to its temperature. The observation of the color of a star could thus be reduced to the measurement of a distance between two points on a photographic plate. The method was used for survey-type work to determine the colors of large numbers of stars, using astrographs with wide fields of view. It was an outcome of the practice in the local scientific milieu cultured by Dunér, which combined an ethos of precise measurement with modern astrophysical observation. Bergstrand continued to pursue the method and tried, after the World War I, to organize an international scheme of standardization to calibrate it. He also worked in photographic photometry of stars and the solar corona.

Among Bergstrand's astrometric contributions was a determination of the ellipticity of the mass figure of Uranus, from the advance of the perihelion of one of its satellites.

Perhaps of greater significance was the fact that Bergstrand fostered a group of young astronomers who later would become very successful in transforming Swedish astronomy. Both **Knut Lundmark** and **Bertil Lindblad** studied at Uppsala University under Bergstrand, as did **Carl Schalén** and **Yngve Öhman**. Especially Lindblad continued and developed Bergstrand's work in stellar spectral photometry, a field that became a corner stone of the observational programs that dominated Swedish astronomy for a major part of the 20th century: the mapping of the structure of the Milky Way with an array of statistical, photometrical, and spectroscopical methods.

Bergstrand's papers can be found at the Uppsala University library.

Gustav Holmberg

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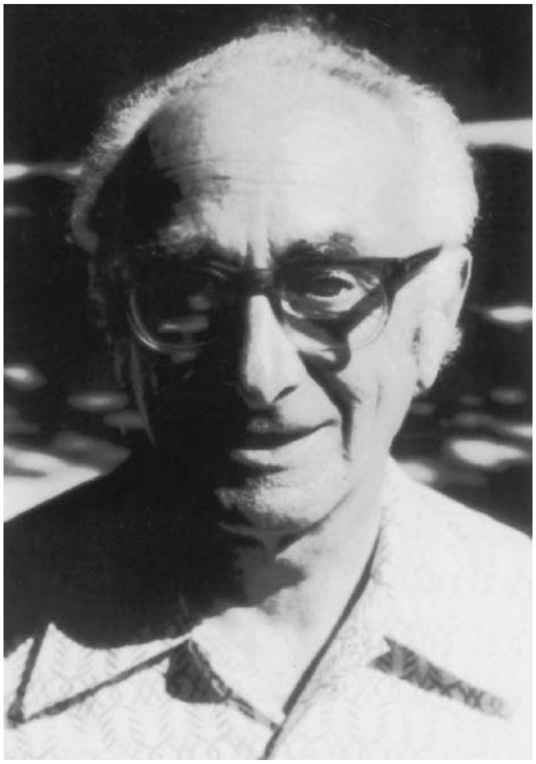
Berman, Louis

Born **London, England, 21 March 1903**
Died **San Francisco, California, USA, 31 January 1997**

American astronomer and educator Louis Berman carried out the first detailed analysis of the spectrum of a star, which showed that it demonstrably had a different chemical composition from that of the Sun. That star, R Coronae Borealis, was very rich in carbon.

Louis Berman was the son of George and Jennie Berman, immigrants from Lithuania to England, who arrived in Saint Paul, Minnesota, when he was 3 years old. Berman entered the University of Minnesota where he earned his AB in 1925 and AM in 1927, and was also assistant at the observatory (1925–1927). He was then awarded a Lick Observatory Fellowship at the University of California where Berman earned his Ph.D. in astrophysics in 1929. By then he had already published six papers, five of them dealing with double stars and one on the orbit and ephemeris of comet C/1925 V1 Wilk-Peltier.



From 1929 through 1968 Berman taught astronomy and mathematics successively at Carleton College, San Mateo Junior College, and the City College of San Francisco. From 1942 to 1945 he served in the United States Naval Reserve where he earned the rank of lieutenant commander. Berman returned to the City College of San Francisco in 1946, officially retiring in 1968, but continuing as a lecturer in astronomy at the University of San Francisco until 1979 and always taking his classes on field trips to Lick Observatory.

While his earlier publications, 21 articles through 1941, dealt mainly with original research on double stars, planetary nebulae, stellar spectra, and novae, after World War II Berman concentrated on teaching and was particularly concerned with introducing non-science-minded students to the essentials of astronomy. From 1942 through 1968 he is cited in astronomical bibliographies as having published only one paper, a book review in 1957 on **Richard van der Riet Woolley**'s *A Key to the Stars*. Three subsequent short articles may still be of interest to laymen and teachers of introductory astronomy. His 1969 *The 80th Anniversary of the Astronomical Society of the Pacific* is a history of a society whose membership is steadily increasing and whose publications have continued to be of benefit to both professional and amateur astronomers. *The Wayward Heavens in Literature* (1970) reveals Berman's extensive knowledge of English literature. This paper should be of lasting interest to educators in both astronomy and literature. He cites more than 20 poets or novelists who have erroneously described celestial objects or events. The "sinners" include Samuel Coleridge, Charles Dickens, Henry Longfellow, **Edgar Poe**, Pearl Buck, and Zane Gray. There is praise for just one poet, Alfred, Lord Tennyson, who refrained from blundering mistakes because he consulted the Astronomer Royal before committing himself to the use of anything astronomical. At a meeting of the American Astronomical Society in San Francisco in 1980, Berman gave an oral presentation *On Teaching a Course: Life on Other Worlds*, of which a mere outline of topics covered has been published.

As a strong advocate of teaching astronomy on a nontechnical basis for nonscience majors, Berman published his textbook, *Exploring the Cosmos*, in 1973. Although highly appreciated, it was written at a time of rapid advancements in astronomy and consequently was soon dated. With the collaboration of John C. Evans, four additional editions were published, in 1977, 1979, 1983, and 1986. Most of the updating was done by Evans. This treatise contains questions not only from scientists but also from poets.

Berman was a member of the American Association for the Advancement of Science, the American Astronomical Society, and the Astronomical Society of the Pacific.

Louis Berman married Esther Goldberg of Saint Paul in 1934. They had one daughter, Susan B. Zimmerman, who became a member of the faculty of City College of San Francisco.

Dorrit Hoffleit

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Bernard of Le Treille

Born **near Nîmes, Gard, France, *circa* 1240**
Died **Avignon, Vaucluse, France, 4 August 1292**

Bernard of Le Treille is known as a medieval European astronomy educator and textbook author who composed an early commentary on **Sacrobosco**'s *Sphere.* A didactic text divided into *lectiones* (lectures), Bernard's *Questiones* on the *Sphere* were presumably composed for use in Dominican schools and take the form of scholastic disputation. In his *Questiones* Bernard expounded the simplified Ptolemaic cosmology presented by Sacrobosco. Bernard's text treated, among other topics, the fundamental Ptolemaic constructions of the epicycle and eccentric, which distinguish **Ptolemy**'s from other geocentric theories such as those of **Eudoxus**. Bernard thus belonged to one of the earliest generations of scholars to assimilate Ptolemaic astronomy and cosmology even before Ptolemy's *Almagest* itself was widely known in Europe. He also discussed the motions of the fixed stars and entered into the arguments over precession and trepidation, reflecting the teachings of his fellow Dominican and contemporary **Albert the Great**. On the issue of celestial causes, Bernard defended the position of **Thomas Aquinas** (another Dominican contemporary) that angels move the celestial spheres by will alone, which was later condemned in 1277 by the Bishop of Paris. Some of Bernard's questions bear upon matters that we would call astrological.

Bernard spent most of his career teaching at various posts in his native southern France – he entered the Dominican Order in Provence – or in Paris, where he studied sometime between 1260 and 1265, and where he taught from about 1279 until 1287. Only two 14th-century manuscript copies of his *Questiones* are known, of which Pierre Duhem published some extracts in French translation.

James M. Lattis

Alternate name

Bernardus de Trilia

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Bernardus de Trilia

➔ **Bernard of Le Treille**

Bernardus Silvestris

➔ **Silvester, Bernard**

Bernoulli, Daniel

Born **Groningen, the Netherlands, 8 February 1700**
Died **Basel, Switzerland, 17 March 1782**

Daniel Bernoulli should rank among the founders of modern mathematical physics, and made important contributions in hydrodynamics, wave physics, and mathematical biology. Daniel was the son of Johann Bernoulli and the nephew of **Jacob Bernoulli**. Though the roots of the Bernoulli family were in Basel, Switzerland, and Daniel's father Johann would have dearly loved to teach at the university there, the chair in mathematics was held by Johann's older brother Jakob. Thus Johann was teaching at the University of Groningen when Daniel was born.

Johann's father forced Johann to study medicine, and Johann rebelled by studying mathematics and physics with his older brother, Jakob. Now Johann forced Daniel to study philosophy and logic, and Daniel likewise rebelled by studying mathematics and physics with his older brother Nicholas. Thus, a second generation of Bernoulli brothers (Daniel and Nicholas) would pursue mathematics and physics.

Bernoulli received his baccalaureate in 1715 and his master's in 1716, then went to study medicine in Heidelberg, Strasbourg, and finally Basel in 1720. A crucial meeting occurred when he went to Venice in 1724. There he met Christian Goldbach, who was sufficiently impressed by the young Bernoulli that he offered him a position at the newly established Russian Academy of Science in Saint Petersburg; an offer was also extended to Daniel's older brother, Nicholas. The Bernoulli brothers arrived in 1725. Unfortunately, Nicholas died from a fever the next year, and Daniel suggested that Goldbach offer an appointment to one of Daniel's friends from the University of Basel, **Leonhard Euler**.

Isaac Newton's *Principia* was published in 1687, but the system of physics it contained was widely rejected outside England. Instead, most physicists adhered to **René Descartes**'s system of vortices, where particles swept endlessly about the Sun, carrying the planets along like leaves in a stream. It had undergone many modifications since the time of Descartes, but its central tenets remained.

There were two main reasons why Newton's theory was not readily accepted. The primary issue was, as **Albert Einstein** pointed out, that gravity required the existence of a sort of "spooky action at a distance." The other was that Newton's physics could *predict*, but not *explain*. For example, the planets all orbit the Sun in the same direction and in very nearly the same plane. Newton's physics could just as easily explain planetary orbits that were not in the same direction and at varying angles of inclination. For Newton, this was not an issue: The fact that it *could* be otherwise but was not gave evidence for the existence of God.

Rather than rely on such arguments, the Paris Academy offered as its prize question for 1732 the explanation of the fact that the planets orbited the Sun in, more or less, the same plane. The academy received no entrants worthy of the prize, so they posed the question anew in 1734, with a double prize. Johann and Daniel entered. To explain the lack of extreme inclinations among the orbits of the planets, Daniel assumed the existence of a solar atmosphere, which was densest not at the surface of the Sun, but instead around the orbit of Jupiter. Further assuming that the solar atmosphere rotated with the Sun would imply that objects moving in planes not parallel to the solar equator would face enormous resistance. (He does not explain details.) Thus only orbits that are parallel or nearly parallel to the Sun's equator would exist.

Unfortunately for Daniel, he and his father were judged equally worthy of the prize. Earlier, Johann's jealousy had poisoned his relationship with his brother Jakob. Now the fact that his son was ranked his equal would poison the relationship between father and son. Daniel himself (probably the only personable member of the mathematical Bernoullis) tried to mend the relationship, but Johann refused to be reconciled, and banned him from the house in Basel, where he returned in 1734 to lecture in botany.

Despite his early training, Bernoulli did not remain a dogmatic Cartesian for long, and was in fact one of the very first to apply the powerful techniques of Leibnizian calculus to the essentially correct axioms of Newton's physics. In 1743, he began to lecture in physiology, but it was not until 1750 that he was finally appointed to the chair of physics, a post he retained until 1776.

Jeff Suzuki

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Bernoulli, Jacob [Jacques, James]

Born **Basel, Switzerland, 27 December 1654**
Died **Basel, Switzerland, 16 August 1705**

Jacob Bernoulli was a member of a family of celebrated mathematicians and physicists; he was a prominent Cartesian. His father and grandfather were spice merchants, and his mother came from a prominent family of bankers and city councilors. He was sent to the University of Basel to study philosophy and theology, taking a degree in philosophy in 1671 and in theology in 1676. Against the wishes of his parents, he also studied mathematics and astronomy, and became the first of the mathematicians among the Bernoullis.

After graduation in 1676, Bernoulli first went to Geneva, then to Paris, where he studied with the followers of **René Descartes** under **Nicolas Malebranche**. Descartes had postulated a vast system of vortices, subtle particles that whirled endlessly around the Sun. This could explain the motion of the planets, and the properties of the vortex could be derived from **Johannes Kepler**'s three laws. However, the system of vortices could not explain comets, and in particular, how the comets could pass through the whirling vortex particles without deflection. An explanation was advanced by Bernoulli in 1680. Rather than have the comets cut through the vortices of the planets, he suggested that a comet was an object that circled a stationary point that lay outside the orbit of Saturn, a system reminiscent of the Ptolemaic system of deferents and epicycles. This was rewritten a number of times, appearing in final form in 1682. Shortly after, Bernoulli wrote *Dissertatio de Gravitate Aetheris* (1683), where he attempted to explain all physical phenomena using the motion of the subtle particles of the Cartesian vortices.

Bernoulli eventually returned to Basel and taught mechanics at the University of Basel from 1683, and became a professor of mathematics in 1687. When Jacob's brother Johann entered the university under parental orders to study medicine, Johann asked Jacob to teach him mathematics; the brothers became early converts to **Gottfried Leibniz**'s calculus. The two attempted to collaborate, but they were both headstrong, arrogant, vindictive, and convinced of the mathematical inferiority of the other, causing them to part as bitter rivals. An impartial observer would judge that Jacob was the better mathematician, and Johann the more creative. Jacob held the chair of mathematics at the University of Basel until his death in 1705.

Jeff Suzuki

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Bernoulli, Johann III

Born **Basel, Switzerland, 14 December 1744**
Died **Berlin, (Germany), 10 July 1807**

Johann Bernoulli III was another one of the famous line of child prodigies of the famous Swiss family of mathematicians and scientists. He was a director of the Berlin Observatory. His father, Johann Bernoulli II (brother of Nikolaus and **Daniel Bernoulli**), succeeded the elder **Jacob Bernoulli**, for whom are named the famous Bernoulli numbers (a sequence of rational numbers that occur in many branches of mathematics), to the chair of mathematics at the University of Basel.

Bernoulli's studies began in law, and at the age of 14 he became a doctor of law. He had already by then shown an extraordinary gift for encyclopedic mastery of diverse subjects well beyond the bounds of his family's mathematical heritage. In 1763, when Bernoulli was still only 19, he was promoted to a chair at the Berlin Academy.

Bernoulli authored several astronomical works full of new and previously unknown details that were not, in and of themselves, particularly important, nor have they since then been generally regarded as such – except that Bernoulli derived them using means that go well beyond the data available through direct empirical observation. Closer scrutiny in fact reveals that what Bernoulli lacked as an observer – he was of poor health and had not very good eyesight – he more than compensated for with his mathematical prowess. In retrospect it is therefore not surprising that one of the greatest rulers of the 18th century, Frederick II (Frederick the Great, king of Prussia), appointed Bernoulli to the post of director of the astronomical observatory in Berlin. Many historians, including some historians of science, have since questioned the appointment. But in Bernoulli's work and letters – nearly 3,000 of which were discovered only toward the end of the 19th century at the Stockholm Academy – one finds avatars for the extension of the observing apparatus by mathematical means, the culmination of which had to await the Fourier series (discovered by Jean Fourier and used to fit sets of data and approximate functions). And although Bernoulli's own work in probability, recurring decimal numbers, the theory of equations, *etc*., did not itself break much new ground, for over a dozen years – from 1776 to 1789 – he published the *Leipzig Journal for Pure and Applied Mathematics*, which served as a unique and extremely important bridge between practical and theoretical mathematics.

Daniel Kolak

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Berossus

Born ***circa* 330 BCE**
Died **probably after 270 BCE**

Berossus was the Babylonian priest of Marduk at the main temple, Esagila, in Babylon, and later moved (probably after 280 BCE) to the Greek island of Cos, a center for medical studies, where he continued his astronomical and astrological teaching. Berossus is neither known to have founded any school in the Greek world, nor is he credited with disciples or students who continued his work.

Berossus's only known literary work is a history of Babylonia written in Greek, most likely composed in Babylon around 280 BCE. His astronomical teachings, published either as a part of his history of Babylonia or as a separate work, were known in the Greek world by the title *Creation*. Only a few of Berossus's theories are known: (1) the Moon is a sphere, only one half of which emits light, and the phases of the Moon are caused by its passing through the orbit of the Sun; (2) there will be a great world conflagration caused by the alignment of the planets (the then five known planets, the Moon, and the Sun) in Cancer; and (3) there will be a great flood caused by the alignment of the planets in Capricorn. His teaching about a world conflagration may have influenced the Stoics and their ideas about a world conflagration. Berossus is credited with the invention of the sundial, and was also famous in Antiquity for his prophecies based on his ability to cast horoscopes. No manuscripts of his prophecies or of his horoscopes survive.

Gerald P. Verbrugghe

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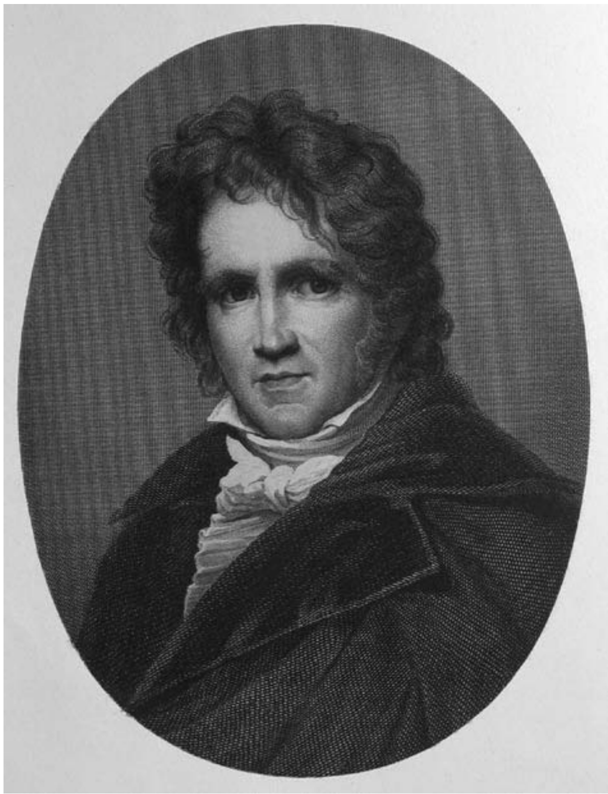
Bessel, Friedrich Wilhelm

Born **Minden, (Nordrhein-Westfalen, Germany), 22 July 1784**
Died **Königsberg (Kaliningrad, Russia), 17 March 1846**



Friedrich Bessel, one of the most skilled astronomical observers of his time, made the first published determination of stellar parallax and distance, produced numerous volumes of his own observations, reduced observations of others, and contributed to advanced mathematics and celestial mechanics. Bessel was one of three sons and six daughters born to Carl Friedrich Bessel, a government secretary, and Friederike Ernestine (*neé* Schrader), daughter of a pastor. In 1812, he married Johanna Hagen (1794–1885); they had one son (Wilhelm, 1814–1840) and three daughters (Marie, 1816–1902; Elisabeth, 1820–1913; and Johanna).

In January 1799, Bessel went to Bremen to contract with the Kulenkamp mercantile firm for a 7-year apprenticeship. In addition to rapidly developing his accounting skills, he trained himself in geography, navigation, mathematics, and astronomy. In 1804, he contacted **Wilhelm Olbers** concerning his determination of the orbit of comet 1P/Halley using data from observations made by **Thomas Harriot** in 1607. Olbers's encouragement, and recognition of Bessel's mathematical abilities, led to the publication of this work and to Bessel's career shift to astronomy when, in 1806, Olbers successfully recommended Bessel for a post as an assistant at a private observatory in Lilienthal (near Bremen) owned by **Johann Schröter**. There, Bessel observed comets and planets, studied atmospheric refraction, and started to reinvestigate the astrometric observations of **James Bradley**.

In 1809, Bessel took two positions that he would keep for the rest of his life – director of King Frederick William III of Prussia's new Königsberg Observatory, and professor of astronomy at Albertus University in Königsberg. Bessel arrived in May 1810 and started lectures that summer. The observatory was completed in 1813, with its first instrumentation purchased from the estate of amateur astronomer **Friedrich von Hahn**. Later additions included a Reichenbach meridian circle (1819), a Fraunhofer heliometer (1829) suitable for very accurate position measurements, and a Repsold meridian circle (1841).

During his 36 years at Königsberg, Bessel taught many students, including **Friedrich Argelander**, Carl Steinheil, and **Heinrich Schlüter**. Bessel contributed significantly to mathematics and physics, developing the Bessel or cylinder functions beyond the work done earlier by **Daniel Bernoulli** and **Leonhard Euler**.

Bessel was ordered to undertake a geodetical survey of East Prussia, performed together with Johan Bayer in 1831/1832 and published in 1838. From the differences between geodetic and astronomical coordinates, Bessel derived the figure of Earth as an oblate spheroid with ellipticity 1/299.15. In 1839, his physical studies led to the introduction of a new Prussian measurement system.

Bessel's first major work in Königsberg was a reduction of Bradley's astrometric observations to a fixed date (1755). Published in 1818, it contained the reduced positions of 3,222 stars, together with a complete theory of spherical astronomy and data reduction. From these observations, supplemented by his own and by those of **Giuseppi Piazzi**, Bessel extracted a list of 71 stars with notable proper motion.

As Bessel became particularly interested in factors impacting the accuracy of measurements, he studied precession, nutation, aberration, and refraction, and developed a theory of errors. His results, summarized in his *Tabulae Regiomontanae*, also contain the positions of two pole stars (α and δ in Ursa Minor) and **Nevil Maskelyne**'s 36 "fundamental stars" from 1750 to 1850. These tables laid the groundwork for precision measurements and theories concerning solar, lunar, planetary, and stellar motions. In 1821, Bessel put forth the notion of the "Personal Equation," the effect of the observer's personality and circumstances on astrometrical measurements (especially the timing of transits) and evidence for suspected variations of the obliquity of the ecliptic. Bessel was also concerned with the quality of his instruments, and effects of instrumental errors on observations, which he thought could be eliminated by expanded data reduction; according to Rudolph Engelmann, Bessel produced at least 23 articles on his investigations of astronomical instruments for angular measurements.

With the new Reichenbach meridian circle, Bessel (together with Argelander) started a project in August 1821 to determine accurate positions for all stars down to the 9th magnitude with declinations between +15° and −15°. In 1825, the range was extended to +45°, and concluded in 1835 with a catalog of 75,011 stars, organized into 536 zones. Later, Argelander continued this work to create the *Bonner Durchmusterung* (Bonn Survey). Also in 1825, Bessel initiated the endeavor to create an accurate atlas, the *Akademische Sternkarten* (Academic star maps), carried out at various observatories and finished only in 1859.

From Bessel's first efforts relating to Halley's comet, he expressed his interest in comets both by observing and by calculating their orbits, improving orbit calculation methods. Following his observations of the return of Halley's comet in 1835, Bessel published a physical theory of comets (1836), stating that comets consist mainly of volatile matter. In 1839, he proposed methods to calculate meteoroid orbits from meteor observations.

Bessel's continued interest in planetary astronomy led him to observe the orbits of the satellites of Jupiter and Saturn (and, in particular, Saturn's satellite Titan) using the Fraunhofer heliometer, resulting in accurate determinations of the masses of the two planets. In 1837, he investigated the theory of Uranus, and supported the hypothesis of another planet further from the Sun. That planet, Neptune, was finally found in the year of Bessel's death.

Bessel's ability to make very precise measurements led to his greatest discovery. After determining with unprecedented precision the position of the vernal equinox and proper motions of nearby stars, Bessel published in 1833 a catalog of 38 double stars, measured with the Fraunhofer heliometer. With that instrument, Bessel became the first to measure and publish (in *Astronomische Nachrichten*, 1838) a stellar parallax, and calculate the distance to a star (double star 61 Cygni) from observations during 18 months in 1837 and 1838. His parallax value of 0.314″, corresponding to a distance of 3.18 parsecs or 10.4 light years, is very close to the modern value of 0.292″, corresponding to 3.42 parsecs (11.2 light years). He had selected 61 Cygni because it had the largest known proper motion. Concerned with the accuracy of his parallax, Bessel redetermined together with Schlüter the parallax of 61 Cygni in 1840, yielding a somewhat less accurate value of 0.348″, corresponding to 2.87 parsecs (9.4 light years). Concurrently, **Thomas Henderson** published a parallax for α Centauri in 1839, derived from observations made in 1832/1833 at the Cape of Good Hope, and in 1840, **Friedrich Struve** of Dorpat presented his (less accurate) parallax for Vega from observations made during 1835–1837.

In 1841, Bessel announced his conclusion, based on variations in their proper motion, that Sirius and Procyon each had an invisible companion. An orbit for Sirius's companion, Sirius B, was calculated 10 years later; the star was eventually found by **Alvan Clark** in 1862 while testing the 18.5-in. objective of a new telescope commissioned for the University of Mississippi. Procyon B was not discovered until 1896 by **John Schaeberle** with the 36-in. telescope at Lick Observatory. Both companions were later revealed to be white dwarfs.

Bessel's scientific publications total at least 400 items addressing most of contemporary astronomy; his particular expertise was precision measurements. Bessel's early works in Lilienthal include observations of comets, asteroids, planets, occultations, eclipses and atmospheric effects as well as instrumental studies; most of them were published in **Johann Bode**'s Berliner *Astronomisches Jahrbuch*.

Bessel was honored during his lifetime by academy memberships (Berlin, Palermo, Saint Petersburg, and Stockholm), by memberships in scientific societies (Edinburgh, Göttingen, Copenhagen, and London), and by memberships in the British Royal Astronomical and Royal Meteorological Societies. Later, he was honored by the astronomical community by the naming of a lunar crater for him (21°.8 N, 17°.9 E; 15.0 km in diameter) in 1935. Minor planet (1552) Bessel was discovered on 24 February 1938 at Turku by **Yrjo Vaisala**.

Hartmut Frommert

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Bethe, Hans Albrecht

Born **Strasbourg, (France), 2 July 1906**
Died **Ithaca, New York, USA, 6 March 2005**

German–American theoretical physicist and astrophysicist Hans A. Bethe received the 1967 Nobel Prize in Physics for his 1939 work that clarified the sequences of nuclear reactions that provided the energy sources for the Sun and other stars engaged in hydrogen fusion (the vast majority of stars). His later significant contributions to astrophysics included providing arguments for a solution to the solar-neutrino problem drawn from weak interaction physics (rather than the details of solar models) and for work on the explosion mechanism of core-collapse supernovae.

Bethe's father was a physiologist and his mother a musician and writer of children's plays. The family moved to Kiel, Germany in 1912 and to Frankfurt in 1915. He graduated from the Goethe Gymnasium in 1924 and spent 1924–1926 at the University of Frankfurt, before moving on to the University of Munich where he received a Ph.D. in 1928 for work with **Arnold Sommerfeld** in theoretical physics. Bethe was an instructor in physics at Frankfurt (1928/1929) and at the University of Stuttgart (1929), where he worked with Paul Ewald, whose daughter Rose he married in 1939. He spent time in Rome (with Enrico Fermi) under a Rockefeller fellowship, also holding positions at Munich and Tübingen (1930/1933). His work in Germany included discussions of the behavior of electrons in metals and of one- and two-electron atoms.

The son of a Jewish mother, Bethe left Germany in 1933, holding temporary positions at Manchester (1933/1934) and Bristol (1934/1935), and working with Rudolph Peierls on the structure of the deuteron (a hydrogen nucleus with a neutron as well as a proton and a vital intermediate stage in the fusion of hydrogen to helium in stars). Cornell University appointed Bethe to an assistant professorship in 1935, and he remained there, retiring as John Wendell Anderson Professor in 1975, with portions of the cold Cornell winters spent in California. His contributions to the early development of nuclear physics were summarized in a series of 1936/1937 review articles with Robert F. Bacher and M. S. Livingston. These were, in effect, a complete text of the field as it then existed and guided experimental work into the war years and beyond.

A pair of 1938/1939 papers, one (on the proton–proton chain) with **Charles Critchfield**, explained the two possible reaction sequences by which stars might convert hydrogen to helium with the liberation of energy. Bethe initially thought that the CN-cycle (also called the carbon cycle, and, later, CNO tricycle) would operate in the Sun and the proton–proton (p–p) chain only in smaller stars. Later work by others made clear that the Sun actually runs on the p–p chain, with the CNO cycle dominant in stars of more than about 1.1 solar masses. A very similar set of reactions was written down in the same time frame by **Carl von Weizsacker**.

Early in World War II, Bethe (on the basis of an encyclopedia article indicating that the armor-piercing mechanism of grenades was not understood) formulated a theory that became the foundation for research on the problem. He was a member of the staff at the Radiation Laboratory at the Massachusetts Institute of Technology (which focused on radar and related studies) in 1942/1943 before becoming chief of the Theoretical Division of Los Alamos Scientific Laboratory (1943–1946). Bethe remained a consultant to the lab for more than 30 years.

Following World War II, Bethe's interests turned increasingly to astrophysics (though he was not, in fact, one of the authors of the short 1948 paper on cosmological nucleosynthesis on which his name appears euphoniously as Alpher, Bethe, and Gamow). He contributed to the equation of state for white dwarfs with Robert Marshak and wrote texts on atomic and nuclear physics relevant to astrophysics with Cornell colleague Edwin E. Salpeter. In the 1970s (following the discovery of neutron stars), Bethe turned his attention to studying the properties of nuclear matter. In 1979, in collaboration with Gerald E. Brown, postdocs, and students, he turned his attention to understanding the mechanism of core-collapse supernovae, where the elements necessary for life as well as neutron stars are produced. Bethe's first key insight was that the entropy was very low and thus neutrons would be confined into atomic nuclei, allowing the collapse to reach and exceed nuclear matter density. Later, analyzing the numerical results of James R. Wilson, he suggested that neutrino energy deposition would be important in the production of a successful supernova explosion. Work on the mechanism continues today.

As early as 1934, Bethe and Peierls had wondered whether the neutrino, first hypothesized by Wolfgang Pauli and named by Enrico Fermi, might ever be observable. They concluded that the answer was probably no, but Bethe followed closely the research undertaken by **Raymond Davis**, Jr. for the detection of solar neutrinos. The detected flux hovered at about one-third of the predicted flux for more than 15 years, while astrophysicists, nuclear physicists, and weak-interaction physicists blamed each other for the discrepancy. In 1986, Bethe quickly saw the implications of a series of papers by S. P. Mikheyev and A. Yu. Smirnov (and related earlier publications by Lincoln Wolfenstein) concerning the possibility that the "flavor" of neutrino (electron) produced in the Sun might rotate into another flavor (the muon neutrino) that would not be detectable by Davis's experiment. A sequence of later observations and experiments in Japan and Canada have shown definitively that this is the right answer, but Bethe's stature in the community was such that most astrophysicists had come around to his point of view well before the definite 2001 data appeared.

Bethe was a classic example of the scientist–statesman. He was one of the founders of the *Bulletin of Atomic Scientists* (devoted to not using the bombs that its founders had helped to develop), and he donated a portion of his Nobel Prize to help establish the Aspen (Colorado) Center for Physics, which he continued to visit and use as a base for both science and hiking for many years. He served as a member of the US delegation to the first, 1958, International Test Ban Conference in Geneva and, with Richard Garwin, wrote an influential article in *Scientific American* that contributed to the adoption of the Anti-Ballistic Missile [ABM] Treaty. When it was later threatened, Bethe wrote a number of popular and technical articles explaining why several proposed forms of missile defense were unlikely to be successful. He was also an advocate of the Comprehensive Test Ban Treaty.

In addition to the Nobel Prize, Bethe received 10 honorary doctorates, the United States National Medal of Science, and other awards from American and German organizations. He was elected to the United States National Academy of Sciences in 1944 and as a foreign member to the Royal Society (London) in 1957. Bethe served as president of the American Physical Society in 1954.

Edward Baron

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Betz, Martha

➔ **Shapley, Martha**

Bevis [Bevans], John

Born **West Harnham near Salisbury, England, 31 October 1695 (or 10 November 1695)**
Died **London, England, 6 November 1771**

John Bevis is best known for his discovery in 1731 of the Crab Nebula, subsequently classified by **Charles Messier** as M1, though Bevis also merits recognition for his important but stillborn atlas, *Uranographia Britannica*.

Bevis was born into a well-to-do family. He studied at Christ Church, Oxford, gaining his B.A. on 13 October 1715 and M.A. on 20 June 1718. It is said that **Isaac Newton**'s *Opticks* was his favorite book during this period. Before settling in London in 1729 and becoming a successful medical practitioner, he traveled widely throughout France and Italy for several years gaining medical information and practical experience.

Astronomy was Bevis's passion; he became friendly with **Edmond Halley**, whom he assisted at Greenwich in observing the transit of Mercury on 31 October 1736. Bevis observed Mercury occulted by Venus at Greenwich in the late evening of 28 May 1737. This difficult observation, with the planets barely 2° above the western horizon, remains the only recorded observation of the occultation of one planet by another.

In early 1738, Bevis moved to Stoke Newington, on the northeast outskirts of London, and constructed an observatory. There, on 6 March, he began to observe the meridian transits of stars. Throughout 1738 and until 6 March 1739, he made transit timings of up to 160 stars per night. Later in 1739, Bevis confirmed the observations by **James Bradley** on the effect of the aberration of starlight. On 23 December 1743, he independently discovered the second-magnitude Great Comet of 1744 (C/1743 X1).

Bevis combined his own transit observations with those in the star catalog of **John Flamsteed** and those made of Southern Hemisphere stars by Halley on Saint Helena, intending to produce a great star atlas more detailed than Flamsteed's *Atlas Coelestis*. Bevis likely started his *Uranographia Britannica* in 1745. Its first mention is in a newspaper advertisement, placed by Thomas Yeoman in the *Northampton Mercury* of 11 April 1748, calling for subscriptions to fund the proposed atlas. Bevis is not mentioned. The publisher listed is John Neale, a London instrument-maker. Later in 1748, Bevis wrote to Abbé **Nicolas de La Caille**, offering to send him a copy of the atlas. This letter and another sent to Bradley, in which he intimates his involvement in "correcting of the press in Mr. Neale's affair," link him directly with the *Uranographia Britannica*. Although Neale financed it, Bevis clearly instigated and compiled the atlas, along with a star catalog and tables to accompany each of the 51 plates. One hundred and eighty-one contributors gave money in exchange for a copy of the atlas or entitlement to purchase individual plates at a reduced cost. In October 1750, John Neale was declared bankrupt. The London Courts of Chancery sequestered the engraved copper plates individually dedicated to the subscribing institutions and individuals. These dedications date the 51 star charts to 1748–1750. The project ended, and the *Uranographia Britannica* never reached publication.

Bevis continued his astronomical observations. He edited Halley's *Tabulae Astronomicae*, published posthumously in Latin (1749) and in English (1752), to which Bevis added supplementary tables. Bevis was one of the first observers to see Halley's comet in May 1759 on its first predicted return to the inner Solar System. He also observed the transits of Venus on 6 June 1761 and 3 June 1769.

In 1750, Bevis was awarded membership in the Berlin Academy of Sciences, perhaps for his eminent contribution to astronomical cartography. On the death of **Nathaniel Bliss** in September 1764, Bevis failed to be elected as the fifth Astronomer Royal, although his name had been put forward. Instead, he reassumed his medical practice, taking chambers in the Middle Temple, London. Bevis was elected to the Fellowship of the Royal Society on 21 November 1765 and became its foreign secretary the following year. Bevis died suddenly in November 1771 after apparently suffering a fall from his telescope while observing a meridian transit of the Sun.

After his death, Bevis's library was left to his executor, James Horsfall, also a fellow of the Royal Society. After Horsfall died in 1785, his wife auctioned his library, including three almost complete atlases, together with plates printed before Neale's bankruptcy. Of these three, one is owned by the American Philosophical Society in Philadelphia, another is at Saint John's College, Cambridge, whereas the third atlas is now missing.

The following year, an anonymous seller offered star atlases entitled *Atlas Celeste* for one and a half guineas apiece. This atlas has neither the star catalog nor tables, nor does it bear any mention of Bevis or of Neale. It does suggest by an anonymous reference to its history and *via* a broadsheet or title page dated 1786 that the *Atlas Celeste* is indeed the surviving core of the unpublished *Uranographia Britannica*. The known atlases, comprising 51 star charts, including northern and southern planisphere charts, frontispiece, and index, are all first impressions, probably made *circa* 1750. Some lack individual plates. Only 10 of the 25 identified atlases have indexes, suggesting that these sheets may have been printed before Neale's bankruptcy.

Few atlases from the *Atlas Celeste* (1786) include the title page. Though it is unknown how many atlases were compiled in 1786, only two with complete title pages are presently known. In total, ten atlases survive in the United Kingdom, eleven in the United States, one in Sweden, and one in Australia. Most are in university or library collections, three in private hands. Two other identified atlases are missing. Several loose plates survive, owned by private collectors or fine-art dealers, as well as many in an important collection of proof copies of certain plates in the map collection of the British Library, London.

Bevis's atlas deserves recognition as a significant contribution to mid 18th-century astronomical cartography. It was the first star atlas to show extended objects, many of which were later cataloged by Charles Messier. It was superior in some respects to previous atlases; it showed many more stars than Flamsteed's *Atlas Coelestis* and was more representationally accurate than **Johann Bayer**'s *Uranometria*. Conversely, Bevis's atlas was the last atlas to be ecliptic-oriented, rather than using the equatorial coordinate system of modern star maps. As such, it would have soon become outdated. Nevertheless, it stands as one of the great, albeit forgotten, star atlases.

Kevin J. Kilburn

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Beyer, Max

Born **Hamburg, Germany, 22 October 1894**
Died **Hamburg, (Germany), 14 November 1982**

In spite of a career as a high school teacher and administrator, and military service in two world wars, Max Beyer was a dedicated amateur comet and variable star observer for over 40 years. For several decades Beyer was the only astronomer studying temporal changes in cometary brightness. His observations thus form an invaluable historical record. He also discovered one comet. Beyer's other original contributions to astronomy include preparation (with professional astronomer Kasimir Graff) of a star atlas to a limiting magnitude of 9.3 that was reprinted in three editions and widely used by variable star observers. In addition to receiving the Donohoe Medal from the Astronomical Society of the Pacific for his comet discovery, Beyer was designated a *doctor honoris causa* by Hamburg University in 1951. A biographical sketch and bibliography appeared in *International Comet Quarterly* 22 (Oct. 2000): 105–114.

Thomas R. Williams

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Bhāskara I

Flourished **Valabhī, (Gujarat, India), 629**

Bhāskara I was an Indian (Hindu) astronomer of the 7th century. The number "I" is added by modern historians in order to differentiate him from his namesake (**Bhāskara II**) of the 12th century. Bhāskara I probably belonged to the Aśmaka country but lived on the western shore of the Gulf of Khambhat (now in Gujarat). Bhāskara I was an ardent follower of **Āryabhaṭa I**, the earliest astronomer of the Hindu classical period (from late 5th to 12th centuries). Bhāskara I composed three works, namely, the *Mahābhāskarīya* (large work of Bhāskara), the *Āryabhaṭīyabhāṣya* (629; a detailed commentary on the *Āryabhaṭīya* of Āryabhaṭa I), and the *Laghubhāskarīya* (small work of Bhāskara). Bhāskara I was a contemporary of another Indian astronomer, **Brahmagupta**, but it is not known whether they knew each other. The classical period produced a number of works that are still considered to be authoritative by traditional Hindu calendar makers.

Bhāskara I belonged to the Ārya School, one of four principal schools of astronomy active during the classical period. The extant works of mathematical astronomy prior to Bhāskara I, namely the *Āryabhaṭīya* of Āryabhaṭa I, and the *Pañcasiddhāntikā* of **Varāhamihira**, are only small, versified compendiums. Thus, Bhāskara I's commentary on the *Āryabhaṭīya* is the earliest detailed prose exposition of mathematical astronomy in India.

The *Mahābhāskarīya* is a systematic textbook of mathematical astronomy; it consists of eight chapters. In this work, planetary motion is explained by means of both epicyclic and eccentric models, in which both *manda*-correction (equation of center) and *śīghra*-correction (annual parallax in the case of outer planets, and the planet's own revolution in the case of inner planets) must be applied. This is a special feature of the *Mahābhāskarīya*. The peculiarity of this method shows that the Hindu model of planetary motion was not a purely geometrical model. Bhāskara I's contemporary, Brahmagupta, used another method, involving successive approximations, to calculate the longitudes of the planets.

The *Āryabhaṭīyabhāṣya* is extant only up to the middle of the sixth verse of Chapter IV in the original *Āryabhaṭīya*. In an edition of this work printed by Kripa Shankar Shukla, the commentary of Someśvara (which summarizes Bhāskara I's commentary) is provided for the rest of the work.

The *Laghubhāskarīya* is a revised and abridged version of the larger *Mahābhāskarīya* and consists of eight chapters.

The works of Bhāskara I were widely employed in India, particularly in South India, from the 7th to the 15th century or so.

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Bhāskara II

Born **Vijjayapura (Bījāpur, Karnātaka, India), 1114**
Died **Ujjain, (Madhya Pradesh, India), 1185**

Bhāskara II was an Indian (Hindu) astronomer of the 12th century. The number "II" is added by modern historians to differentiate him from his namesake (**Bhāskara I**) of the 7th century. Bhāskara II is frequently called Bhāskarācārya (Master Bhāskara). He probably lived in Vijjayapura; his father was Maheśvara who was also an astronomer. Bhāskara II composed several works on astronomy, most notably the *Siddhāntaśiromaṇi* (1150), along with his own commentary, the *Vāsanābhāṣya* or *Mitākṣarā*, the *Karaṇakutūhala* (1183), and the *Vivaraṇa* on the *Śiṣyadhīvrddhidatantra* of **Lalla**.

Bhāskara II's grandson, Caṅgadeva, founded an institution for the study of the *Siddhāntaśiromaṇi* that received an endowment in 1207 from the king, Soïdeva the Nikumbha. Bhāskara II's lineage produced several noted astronomers and astrologers who promoted these teachings.

Bhāskara II was a follower of the Brāhma School of **Brahmagupta**, one of four principal schools of astronomy active during the classical period (from late 5th to 12th centuries). He was the last great figure of Hindu astronomy, preceding the introduction of Islamic astronomy in the 13th and 14th centuries.

The *Siddhāntaśiromaṇi* was written when Bhāskara II was 36 years old and forms a comprehensive treatise of mathematics and astronomy. It consists of two principal parts: (1) the *Grahagaṇitādhyāya*, which contains 12 chapters on the motions of the planets, problems of time and direction, lunar and solar eclipses, conjunctions, and so forth; and (2) the *Golādhyāya*, which contains 13 chapters, chiefly on the celestial sphere. This latter text also contains a discussion of the precession of the equinoxes. Here, Bhāskara II seemingly refers to a lost work of **Maṇjāla**, as Bhāskara II's theory of precession is not contained in any extant work of Maṇjāla.

The *Karaṇakutūhala* is a practical work of astronomy and consists of ten chapters that provide simplified rules and methods for solving astronomical problems.

Bhāskara II's *Vivaraṇa*, the commentary on the *Śiṣyadhīvrddhidatantra*, is a textbook belonging to the Ārya School of astronomy.

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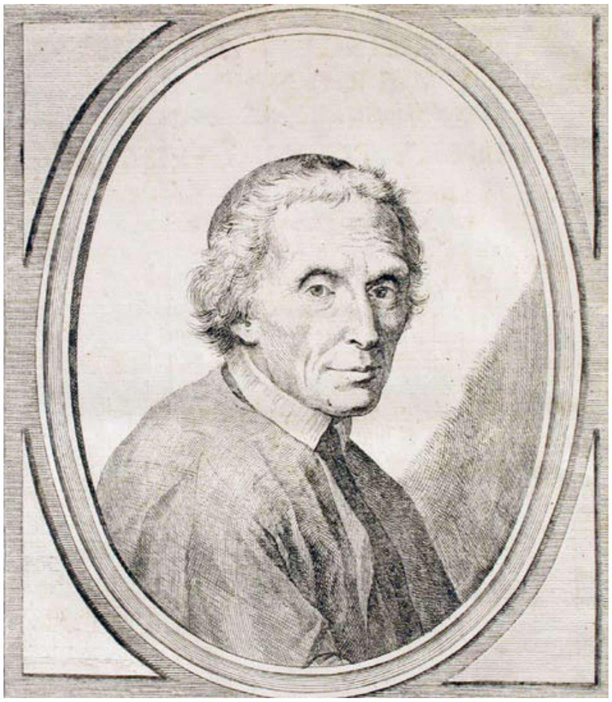
Bianchini, Francesco

Born **probably Verona, (Italy), 1662**
Died **Rome, (Italy), 13 February 1729**



Francesco Bianchini was an observational astronomer, a discoverer of three comets, who published his account of observations of Venus. Bianchini was a papal officer in Rome and librarian to Cardinal Ottoboni (later Pope Alexander VIII). Bianchini's observations were carried out chiefly at Albano, the supposed site of the Alba Longa. Some idea of his skill, assiduity, and sagacity can be obtained from a selection of these observations edited, with a preface, by **Eustachio Manfredi** of Bologna (with a portrait of Bianchini as a frontispiece), published posthumously at Verona in 1737.

Bianchini discovered three comets: One was discovered on 30 June 1684, of which he was not only the discoverer but also the sole observer (C/1684 N1); another was a codiscovery on 20 April 1702 (C/1702 H1); and a third was on 17 October 1723, but which had already been seen, notably by William Saunderson, at Bombay (C/1723 T1). That of 1684 was last seen on 19 July, and its orbit was one of those determined by **Edmond Halley**. Bianchini's attempt to measure the parallax of Mars at its opposition in 1685 gave a result not quite two-thirds of the true value. He observed many eclipses of the Moon, and saw the solar eclipse of 22 May 1724. He studied Jovian satellite phenomena, and made numerous drawings of the mountains and craters of the Moon, being credited with the discovery of the great Alpine Valley.

Hesperi et phosphori nova phaenomena, sive observationes circa planetam Veneris, the work for which Bianchini is principally known, was published at Rome in 1728. It details his meticulous studies of the fugitive markings of Venus, and fixed the diurnal spin rate of the planet at 24 days 8 hours. His chart of the markings honors Christopher Columbus, **Galileo Galilei**, Henry the Navigator, **Amerigo Vespucci**, and others. However, he was utterly mistaken in his assumptions. His book is today best known for two often-reproduced plates of aerial telescopes, of extremely long focal length, with lenses by **Giuseppe Campani**. Bianchini's attempt to measure the diurnal parallax of Venus in July 1716, which gave a result of 14.3″ (near to the modern value), is of more permanent interest. His last recorded observation was of the lunar eclipse of 13 February 1729.

Richard Baum

Alternate name

Blanchinus, Francisco

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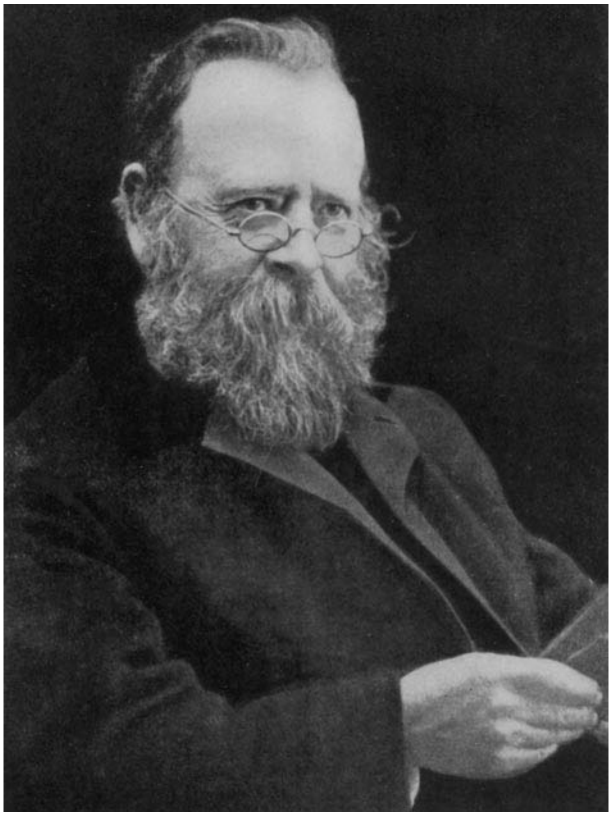
Bickerton, Alexander William

Born **Alton, Hampshire, England, 7 January 1842**
Died **London, England, 22 January 1929**



Alexander Bickerton was a controversial and flamboyant figure in British and New Zealand astronomy, a fine teacher and popularizer, but exponent of unconventional ideas (now known to be wrong). He was the son of Richard Bickerton and Sophia Matilda (*née* Eames) and was educated at Alton Grammar School and at the Royal School of Mines and Royal College of Chemistry in London. He married, in 1865, Anne Phoebe Edwards (died: 1869) and in 1920 Mary Wilkinson.

Bickerton studied science subjects at the Royal School of Mines in South Kensington, London, from 1866, where his considerable academic successes resulted in Bickerton himself giving public lectures. Then, after teaching at the Hartley Institute in Southampton for 3 years, he accepted the position of professor of chemistry in 1874 at the recently founded Canterbury University College in Christchurch, New Zealand. Bickerton stayed there until 1902, when he was eventually dismissed by the college council, ostensibly for poor management, but in reality for his unconventional scientific views and social mores. His most famous student at Canterbury was **Ernest Rutherford**.

Bickerton's astronomical reputation rests almost entirely on his theory of partial impact, in which he attempted to account for the phenomenon of novae by the proposal that two stars in an oblique impact would result in a third and highly luminous body being removed by tidal interactions. The theory was later extended to account for other types of variable stars, double stars, the origin of the Solar System, planetary nebulae, and even evolution of the Milky Way. His ideas lacked mathematical detail and were widely shunned by the scientific establishment. Both *Nature* and the Royal Astronomical Society, London, rejected Bickerton's papers, but he continued to promote his partial impact theory through popular lectures, at which he excelled, as well as through articles in the *Transactions of the New Zealand Institute* and the magazine *Knowledge*.

Thomas Chamberlin and **Forest Moulton** further developed the idea of stellar collisions or near approaches as a way of forming planetary systems. A stellar collision model of supernovae was put forward by **Fred Whipple** in 1939, and one for quasars in the early 1960s. The phenomenon is now thought to be important only in dense clusters of stars and near the centers of galaxies, and Bickerton's work has not been credited by anyone working on these topics in recent years.

After leaving Canterbury University College, Bickerton returned to Britain where he founded the London Astronomical Society, of which he became the president. He also wrote a series of popular books on astronomy, including the *Romance of the Heavens* in 1901.

From the point of view of astronomical history, Bickerton's work is now largely forgotten. From the point of view of the intellectual and social development of the early Canterbury settlement in New Zealand, he is still remembered for the excellence of his teaching, the notoriety of his social nonconformity, and the bitter battles he fought with the college council.

John Hearnshaw

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Biela, Wilhelm Freiherr von

Born **Rossla near Stolberg, (Sachsen-Anhalt, Germany), 19 March 1782**
Died **Venice, (Italy), 18 February 1856**

Wilhelm von Biela is noted for a short-period comet that bore his name (now known as 3D/Biela) and broke into fragments that, for several returns, created spectacular meteor showers. Biela served as an officer in the Austrian army, eventually rising to the rank of Major. He participated in a number of military campaigns against Napoleon between 1805 and 1809. After the Napoleonic Wars, Biela served in numerous places, including Prague and Josephstadt, Bohemia, and Naples and Vicenza, Italy. Eventually, he was appointed commandant of Rovigo, Venetia, a post from which he retired in 1846 to live out his life in Venice after suffering a stroke.

During the period of his military service, Biela was an active amateur astronomer, having attended the astronomical lectures of Alois David in Prague while recuperating from war-related injuries. Biela made independent discoveries of three comets, in 1823, 1827, and 1831, of which those in 1823 and 1831 were codiscoveries of comets that had been observed some days earlier by other astronomers. Biela's only original discovery, and his most interesting one, was the comet of 1826 (3D/1826 D1). It was discovered on 27 February in the constellation of Aries while Biela was observing from Josefstadt. When Biela calculated the comet's orbit, he found it to have a short period of 6.62 years. He also recognized that former appearances of this comet had been observed in 1772 (Jacques Laibats-Montaigne and **Charles Messier**) and 1805 (**Jean Pons**). It became known as Biela's comet (only the third comet to have been shown to be periodic by observations on different appearances). Comet Biela was observed telescopically as it decayed into two comets in 1846, and seen visually for a last time in 1852. Its fragments are probably the source of a meteor shower called Andromedids, or Bielids, first observed in spectacular showers in November 1872 and November 1885 but occurring only sporadically since 1940.

Biela published several astronomical papers, mainly on his comet observations and calculations, most of which appeared in the *Astronomische Nachrichten*. In addition to the three comets in the discovery of which he was involved, his papers include observations of a light pillar emerging from the Sun after sunset, sunspot observations, some theoretical considerations on comets falling into the Sun, historical studies on comets and **Tycho Brahe**, and stellar occultations by the Moon. In his 1836 monograph, *Die zweite grosse Weltenkraft*, Biela attempted to develop a theory to explain supposed relations between planetary rotation and satellite revolution periods, a popular theme in the 19th century.

Biela was honored by having his name assigned to the minor planet (2281) Biela. His name also lives on in his eponymous comet, and in one of the designations of the meteor shower formed by the remainder of that comet, the Bielids.

Hartmut Frommert

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Biermann, Ludwig Franz Benedikt

Born **Hamm, (Nordrhein-Westfalen), Germany, 13 March 1907**
Died **Munich, (Germany), 12 January 1986**

German astrophysicist Ludwig Biermann gave his name to a method of generating magnetic fields in strongly ionized gas (the Biermann battery) and also introduced mixing length theory into stellar structure and developed our initial understanding of ionization and acceleration of comet tails.

Biermann obtained his Ph.D. from Göttingen University in 1932, following initial studies at Munich (1925–1927) and Freiburg (1927–1929). He was an exchange scholar at Edinburgh (1933/1934) and, following his *habilitation* at Jena (1934–1937), held positions at the Hamburg University and Observatory. At the end of World War II, Biermann served as a principal author for the Field Information Agencies Technical [FIAT] report on the state of German science during the war years (1948), summarizing work on opacity and stellar interior structure. He was appointed the head of the newly formed Max Planck Institute for Astrophysics in Göttingen – later relocated to Munich – after the restructuring of the Kaiser Wilhelm Institute into the Max Planck Institute [MPI] at the end of the war (1948), a post he held for the rest of his life. Among the younger people he mentored at the MPI were Aarnulf Schluter, Eleonora Trefftz, Reimer Lüst, Rhea Lüst (his collaborator in understanding comet tails), Rudolf Kippenhahn, Friedrich Meyr, and Stefan Temesvary.

Biermann's first important work centered on stellar interior structure and convection, beginning with a series of papers on stellar models starting in 1931. These were elaborated in his *habilitation* thesis for Jena in 1935, where he demonstrated that the Schwarzschild sriterion, applied in radiative stellar interiors, leads to vigorous convection, restricting the superadiabatic gradient to extremely small values (of order one part in a million). Since the adiabatic temperature gradient depends only on the equation of state through the exponent of the barotropic (pressure–density) relation, the result provided a simple, reliable prescription for computing energy transport in stellar convection zones and made possible efficient numerical computation of stellar interior models. Biermann also studied convection in rotating stars and, along with **Thomas Cowling**, models for centrally condensed stars that mimic the structure expected for red giants. Although Biermann and Cowling did not meet until the 1952 Rome general assembly of the International Astronomical Union, they had corresponded regularly about their work on stars during the 1930s. Biermann was the first to apply Ludwig Prandtl's concept of mixing length (a sort of macroscopic mean free path) to calculate the transport of energy by convection. His student Erika Böhm-Vitense developed the modern version of mixing length theory [MLT] in the early postwar years.

Throughout his career, but especially during the 1940s, Biermann maintained an interest in atomic physics. Recognizing the need for quantitative data on opacity and abundances for the proper modeling of the solar interior and atmosphere, he was thus involved in a program to compute oscillator strengths for intermediate mass ions such as sodium, potassium, magnesium, silicon, and aluminum; these were among the first such computed data.

During the 1950s, Biermann studied the dynamics of ion (type I) cometary tails, assuming the observed accelerations were due to collisional momentum transfer from the outer solar atmosphere. These observations, confirmed by satellite measurements by 1961, proved pivotal to the discovery of the solar wind. He demonstrated that the velocity of the comet produces an aberration of the tail relative to the outflow, although the density he derived, of order 10^3 cm^{-3}, was later revised by *in situ* measurements to about 1 cm^{-3}. The deviation resulted from Biermann's neglect of the magnetic field structure, later shown to be the dominant factor in controlling the outflow. Nevertheless, this prediction proved fundamental in the determination of the rate of both mass and angular momentum loss from the Sun (and, ultimately, all solar-type stars) and served as the earliest demonstration of the existence of the solar wind, later theoretically explained by Eugene Parker (1958, 1963).

Biermann's later work on comets focused on the loss of hydrogen and Lyman α-scattering halos around cometary nuclei, disconnection events in tails, and the interaction of the cometary plasma with magnetic fields transported outward by the solar wind. Much of this work is continuing using detailed numerical magnetohydrodynamic modeling. He was also involved in design of the plasma experiments and camera for the European Space Agency's Giotto cometary rendezvous mission for comet 1P/Halley, some of the results of which appeared posthumously.

Always interested in astrophysical applications of plasma physics, Biermann and A. Schluter introduced a diffusive model for generation of magnetic fields in strongly ionized environments, known as the "Biermann battery" mechanism that has recently found applications in models for magnetic field generation in the early Galaxy. In the formative period, he played an important role in calling astronomers' attention to developments in magnetohydrodynamics during a number of meetings of the Cosmic Gas Dynamics series in the 1950s.

Biermann's honors include the Bruce Medal of the Astronomical Society of the Pacific (1967), Gold Medal of the Royal Astronomical Society (1974), and the Karl Schwarzschild Medal of the Astronomische Gesellschaft (1980). He was a member or associate of scientific academies in West Germany, East Germany, Belgium, and the United States. The Biermann prize of the Astronomische Gesellschaft is named in his honor. His son, Peter, is also a theorist who carried out pioneering modeling studies of interacting (mass-exchanging) close binary systems and cosmic-ray acceleration.

Steven N. Shore

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Bigourdan, Camille Guillaume

Born **Sistels, Tarn-et-Garonne, France, 6 April 1851**
Died **Paris, France, 28 January 1932**

French astrometrist Guillaume Bigourdan specialized in problems of precise measurement and dissemination of time and directed the Bureau international de l'heure [BIH] for the first decade of its existence. Bigourdan was the son of Pierre Bigourdan and Jeanne Carrière, part of a peasant family whose name derives from a 7th-century association with land owned by the Comté de Bigorre. He began school in the town of Valence d'Agen and continued in Toulouse, where his aptitude drew the attention of **Francois Tisserand**, then professor of astronomy and director of the Observatoire de Toulouse. Bigourdan joined the Toulouse staff in 1877, and went on to Paris in 1879 when Tisserand moved there, marrying Sophie, the eldest daughter of admiral **Ernest Mouchez**, with whom he had nine children.

Bigourdan completed a doctoral thesis with Tisserand on the effects of the "personal equation" (errors in determination of times of astronomical events like meridian crossings, which vary systematically from one observer to another) on measurements of double stars. He also compiled a catalog of nebulae and used meridian-circle telescopes for time determinations. France adopted "zone time" in 1891, and in 1911 switched from zones centered on Paris to ones centered on the Greenwich, England meridian defined by **George Airy**. Bigourdan participated in defining the new time zones and longitudes, and, with Gustave Ferrié (1868–1932) pioneered the dissemination of wireless telegraphy time signals from the Eiffel Tower over a distance of 5,000 km.

During World War I, with the support of **Benjamin Baillaud**, then director of the Paris Observatory, Bigourdan took over the operation of the time service unofficially. The BIH was established officially in 1919 during the first, organizational meeting of the International Astronomical Union in Brussels, in which both

Baillaud and Bigourdan participated. Bigourdan was appointed its first director, holding the job until 1929. In addition to his work in timekeeping, he carried out a variety of research in the history of astronomy, publishing on the history of the Bureau des longitudes, the Observatoire de Paris, the metric system, and French observatories and astronomers, particularly **Alexandre Pingré**.

Bigourdan was elected to the Académie des sciences in 1904 and served as both its vice president and president (1924). He received the Gold Medal of the Royal Astronomical Society, the *Légion d'honneur*, and several other honors for his work on time standards.

Jacques Lévy

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Billy, Jacques de

Born **Compiègne, (Oise), France, 18 March 1602**
Died **Dijon, France, 14 January 1679**

Jacques de Billy was an astronomical writer, who also made contributions to mathematics, particularly number theory and Diophantine analysis. After studying humanities, he entered the Jesuit order in 1619 and completed his divinity studies, equivalent to a doctorate, in 1638. He taught theology and mathematics at a number of Jesuit colleges in northeastern France, ending his career in Dijon.

Between 1656 and 1670 Billy wrote at least three major works on astronomy in Latin: an advanced text book, a publication on eclipses entitled *Tabulae Lodoicaeae* (because it was dedicated to Louis XIV, the Sun King), and a book on the crisis in cometary motions. No one knew whether comets moved in straight lines, circular orbits, or some other variant, a confusion brought to the fore by the bright comets of 1664 (C/1664 W1) and 1665 (C/1665 F1). Billy also wrote *Le Tombeau de l'Astrologie Judiciaire* in which he condemned astrology and the casting of horoscopes. Among his manuscripts preserved in Dijon is an ephemeris of the comet of 1590 (C/1590 E1).

Peter Broughton

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Biot, Edouard-Constant

Born **Paris, France, 1803**
Died **1850**

French engineer Edouard-Constant Biot was the son of astronomer **Jean-Baptiste Biot**. He cataloged the meteors, comets, and novae that appear in ancient Chinese records. Biot's catalog was useful in associating the Crab Nebula with the supernova of 1054.

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Biot, Jean-Baptiste

Born **Paris, France, 21 April 1774**
Died **Paris, France, 3 February 1862**

Jean-Baptiste Biot's achievements in optics, geodesy, and geophysics improved the scientific grounding of astronomy. He proved the extraterrestrial origin of the meteorites and helped to unify the precise mathematics of astronomy with the experimental techniques of physics. Biot's father Joseph, a Parisian bourgeois, wanted him to go into commerce. However, around 1791, after taking humanities at the Collège Louis-le-Grand, Biot began to study analysis and calculus. Briefly enlisting in the revolutionary army, he fought as a gunner in the 1793 battle of Hondschoote. Next year he entered the École des Ponts et Chaussées. He transferred to the École Polytechnique as soon as it opened and shone as a student, gaining the respect of faculty members such as Gaspard Monge and Gaspard-Marie Riche de Prony. On graduation Biot won a professorship of mathematics at Beauvais in February 1797 and then married Gabrielle Brisson, the 16-year-old sister of fellow Polytechnicien Barnabé Brisson. Mentored first by the young mathematician Sylvestre Lacroix and then by the celebrated **Pierre de Laplace**, Biot penned an arithmetic textbook and several scientific memoirs. In May 1800, backed by Lacroix, **Joseph Lagrange**, and Laplace, Biot joined the Institut de France as a nonresident associate of its First Class (later reborn as the Académie des sciences) and was elected a full member in 1803, replacing **Jean Delambre**. In November 1800, Biot became professor of mathematical physics at the Collège de France, allowing him to become one of the most active investigators of the First Class. In 1809, Biot was appointed professor of astronomy at the science faculty of the Université de France; he was dean from 1840 until his retirement in 1849. A member of the Société d'Arcueil, Biot espoused its cochair Laplace's hopes of bringing astronomical accuracy and the language of mathematics to French experimental physics.

In optics, Biot attempted to explain polarization of light using corpuscular theory, but his experimental work also included measurements of terrestrial magnetism, gas densities, heat diffusion, and the speed of sound in various media. Research with Félix Savart subsequent to H. C. Oersted's discovery of the connection between electricity and magnetism yielded the Biot–Savart law relating the intensity of the magnetic field set up by a current flowing through a wire to the distance from the same wire. Other investigations in mathematics, electricity, and plant physiology were of less consequence, but Biot lent vital support to young Louis Pasteur's work on the polarizing power of molecules, the first intimation of molecular chirality.

It is unclear when Biot became interested in astronomy, though he later recounted that he first communicated with Laplace to read the unbound pages of his *Mécanique céleste* as they were printed. He repeated all the calculations and probably discussed the more difficult ones with Laplace. This led to the publication of his first significant astronomical work, the *Analyse du Traité de mécanique céleste de P. S. Laplace* in 1801.

Biot's first original research was a thorough investigation of the alleged fall of stones from the sky near l'Aigle in the Orne department in April 1803. When he reported back to the Institut in July, presenting testimonies, samples, and the results of chemical analyses, Biot established the reality of meteorites over the earlier objections of rationalists.

Biot's most concrete contributions were in the field of geophysics and geodesy. A balloon ascension with J. L. Gay-Lussac in August 1804 tested the variation of the Earth's magnetic field with altitude and found no change up to 4,000 m. In a joint 1804 memoir with **Alexander von Humboldt**, Biot presented a theory of the magnetic field that agreed with part of Humboldt's readings and stimulated others to produce a better general theory. Biot later observed the lack of polarization of the aurora borealis, concluding that the phenomenon could not result from either reflection or refraction.

In 1806, Biot and **François Arago** were charged by the Bureau des longitudes with the measurement of an arc of the meridian in Spain to improve the value of the meter, still defined at that time as the ten-millionth part of a meridian quadrant of the Earth. Biot had previously worked with Arago on the refractive indices of various gases, and their result for air matched Delambre's value derived from astronomical considerations to a high degree of precision. Biot would later return to the problem of atmospheric refraction.

Between 1806 and 1825, Biot was part of several efforts to extend geodesic measurements, from the Balearic Islands to the Shetlands, and to make additional determinations of gravitational acceleration in several localities. The main results were included in the 1821 *Recueil d'observations géodésiques, astronomiques et physiques* coauthored with Arago. The results of his later geodesic work in Italy and Sicily were published in an 1827 memoir. The pendulum observations along selected parallels of longitude did not confirm expectations, pointing out the inadequacy of the simple ellipsoidal theory of the Earth's shape.

By 1822, however, Biot had developed an interest in ancient astronomy, which resulted in a paper on the Egyptian zodiac discovered at Denderah. He went on to publish on ancient chronology and compare the astronomical notions of the ancient Egyptians, Chinese, and Chaldeans. A later work on Hindu astrononomy sought to subordinate it to Chinese and Greek achievements, but its seemingly definitive conclusions relied overmuch on an atypical source. Biot's work on Chinese chronology is still cited occasionally, though 20th-century scholarship has invalidated some of its conclusions.

A noted textbook writer, Biot put out three editions of his *Traité élémentaire d'astronomie physique*, which grew to comprise six volumes and an atlas. While eschewing higher mathematics, the *Traité* was extremely detailed and incorporated the latest results of turn of the century research. Sir **George Airy**, later head of Greenwich, cited it as the spark of his interest for astronomy.

In later years, Biot's antiquarian work on Egyptian and Chinese astronomy won him election to the Académie des inscriptions et belles-lettres in 1841. His writings, mainly in history of science, earned him a seat at the Académie française in 1856, making him one of the very few figures in the history of the Institut to have achieved triple recognitions as scientist, historian, and author. Awarded the *Légion d'honneur* in 1814, Biot went on to become an officer (1823) and a commander (1849) of the order. He was elected a fellow of the Royal Society in 1815.

Biot's wife died before him, as did his son Édouard, who belonged to the Académie des inscriptions et belles-lettres. Biot completed the work on Chinese astronomy begun by and with his son.

A conservative monarchist in later life, Biot mostly stayed aloof from party politics, within and outside the Institut, though he served as mayor of the small town of Nointel in the Oise department. Having long been a skeptic in religious matters, Biot gradually returned to the Catholic faith in his fifties.

Jean-Louis Trudel

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Birjandī: ʿAbd al-ʿAlī ibn Muḥammad ibn Ḥusayn al-Birjandī

Died **1525/1526**

Birjandī, a pupil of Manṣūr ibn Muʿīn al-Dīn al-Kāshī (who was a staff member of the Samarqand Observatory) and of Sayf al-Dīn Taftāzānī, was known for his numerous astronomical commentaries and supercommentaries. He wrote several commentaries on the works of **Naṣīr al-Dīn al-Ṭūsī**, including Ṭūsī's *al-Tadhkira fī ʿilm al-hay'a*, his *Taḥrīr al-Majisṭī* (recension of **Ptolemy**'s *Almagest*), and Ṭūsī's book on astrolabes. In the preface to the last book Birjandī mentions some tables of the positions of stars that he calculated for the year 853 Yazdigird (1484). In addition, Birjandī wrote a commentary on **Kāshī**'s *Zīj-i Khāqānī*, which was Kāshī's attempt to correct Ṭūsī's *Īlkhānī Zīj*. Birjandī was also known for his commentary on the *Zīj* of **Ulugh Beg** (the last date provided in it being 929 H = 1523) as well as for his supercommentary *(ḥāshiya)* on **Qāḍīzāde**'s commentary *(sharḥ)* to **Maḥmūd al-Jaghmīnī's** *al-Mulakhkhaṣ fī ʿilm al-hay'a al-basīṭa*.

In addition to these commentaries, Birjandī wrote several independent astronomical works, whose subjects included cosmology, ephemeredes, instruments of observation, as well as a treatise on the distances and sizes of the planets that was dedicated to Ḥabīb Allāh, and another work on the construction of almanacs completed in 1478/1479.

Birjandī completed his *Sharḥ al-Tadhkira* (Commentary on the *Tadhkira*) in 1507/1508. Nayanasukha translated the 11th chapter of the second book of this work into Sanskrit. This is the chapter in which Ṭūsī deals with the device called the "Ṭūsī couple" and its applications, mainly to the lunar theory. From the colophon of the Sanskrit translation we learn that a Persian, Muḥammad Ābida, dictated it (presumably in a vernacular language) to Nayanasukha as he composed it in Sanskrit. Muḥammad Ābida had been at **Jai Singh**'s court since at least 1725.

Birjandī's commentary on the *Tadhkira* is a good example of the commentary tradition within Islam. In analyzing Ṭūsī's work, Birjandī provides the reader with explanations of meanings, shows variants, provides grammatical explanations, and engages in philosophical discussions. He also provides different interpretations and examines the objections of his predecessors against Ṭūsī. In Book II, Chapter 11, Birjandī cites the following authors and works: Ṭūsī's *Risālah-i muʿīniyya*; Ptolemy's *Almagest*; **Ibn al-Haytham**; Euclid's *Elements*; **Quṭb al-Dīn al-Shīrāzī**'s *Tuḥfa* and *Nihāya*; **Theodosius**'s *Sphaerica*; **Menelaus**; and **Autolycus**.

In his commentary, Birjandī seems to follow Shīrāzī's opinions and his devices. For example, Birjandī mentions an objection against the application of the Ṭūsī couple to the celestial spheres regarding the necessity of rest between two motions; such a discussion about rest between ascending and descending motions is given by Shīrāzī as well as **Shams al-Dīn al-Khafrī** (Ragep, pp. 432–433). Also when Birjandī discusses an application of the curvilinear or spherical version of the Ṭūsī couple, he mentions that this version produces a slight longitudinal inclination, which had been discussed by Shīrāzī in his *Tuḥfa* (Kusuba and Pingree, pp. 246–247). Finally we note that Birjandī gives a proof for a device that G. Saliba has called the "ʿUrḍī lemma," after **Mu'ayyad al-Dīn al-ʿUrḍī**, but the proof is similar to that given by Shīrāzī rather than ʿUrḍī's original in his *Kitāb al-Hay'a*.

Takanori Kusuba

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Birkeland, Kristian Olaf Bernhard

Born **Christiania (Oslo, Norway), 13 December 1867**
Died **Tokyo, Japan, 15 June 1917**

Kristian Birkeland, perhaps Norway's most famous scientist, produced the first artificial aurorae, organized polar expeditions to collect auroral data, and contributed to the theoretical understanding of these upper atmospheric phenomena.

Birkeland was the son of Reinart Birkeland and Ingeborg (*née* Ege). His one brother, Tonnes Gunnar, was a medical doctor, and one of his cousins, Richard Birkeland, became professor of mathematics at the University of Oslo. Kristian Birkeland received his early education in Norway, at the University of Oslo, was appointed to a position there in 1893, and became full professor at the age of 31. He was elected to the Norwegian Academy of Science and Letters and received an honorary doctorate from the Technical University of Dresden, Germany, in 1909.

Birkeland published his first three scientific papers (in mathematics) before he was 20. Among his early contributions to physics was his work on Maxwell's equations with the first solution in 1894 as well as a general expression – still valid – for the Poynting vector in 1895.

In 1896, Birkeland published, through the French Academy journal *Comptes rendus de l'Académie des sciences*, the first realistic auroral theory. His idea was that electrically charged particles (which he called cathode rays, because the electron had not yet been discovered) streamed out from sunspots at such high velocity that, guided by the Earth's magnetic field, they could penetrate far into the polar atmosphere. *Via* collisions with the atmospheric gases, visible aurorae would be produced.

Birkeland produced the first artificial aurorae in his laboratory in 1896. In order to substantiate his theory, Birkeland began rather complicated calculations of charged particles in magnetic fields.

He also built the world's first permanent auroral observatory, in northern Norway, in 1899.

Birkeland organized expeditions to polar regions where he established a network of observatories under the auroral regions to collect aurora and magnetic field data. The results of the Norwegian polar expedition conducted from 1899 to 1900 contained the first determination of the global pattern of electric currents in the polar region from ground magnetic field measurements.

Birkeland suggested that the polar electric currents – today referred to as auroral electrojets – were connected to a system of currents that flowed along geomagnetic field lines into and away from the polar region. He provided a diagram of field-aligned currents in his famous book, *The Norwegian Aurora Polaris Expedition 1902–1903*. The book also contains chapters on magnetic storms and their relationship to the Sun, the origin of the sunspots themselves, comet 1P/Halley, and the rings of Saturn.

Birkeland's vision of field-aligned currents became the source of a controversy that continued for half a century, because their existence could not be confirmed from ground-based measurements alone. The absolute proof of Birkeland's field-aligned currents could only come from observations made above the ionosphere with satellites. A magnetometer onboard a US satellite, launched in 1963, observed magnetic disturbances on nearly every pass over the high-latitude regions of the Earth. The magnetic disturbances were originally interpreted as hydromagnetic waves, but it was soon realized that they were due to field-aligned or Birkeland currents, as they are called today. Birkeland even estimated the total currents at 10^6 A – still a realistic value.

The scale of Birkeland's research enterprises was such that the time-honored matter of funding became an overwhelming obstacle. Recognizing that technical invention could bring wealth, he spent much time on applied science. In 1900, he obtained patents on what we now call an electromagnetic rail gun and, with some investors, formed a firearms company. The rail gun worked, except the high muzzle velocities he predicted (600 m/s) were not produced. At one demonstration, the coils in the rail gun shorted and produced a sensational inductive arc complete with noise, flame, and smoke. It easily could have been repaired and another demonstration organized.

However, fate intervened in the form of an engineer named Sam Eyde. Eyde told Birkeland that there was an industrial need for the biggest flash of lightning that can be brought down to Earth in order to make artificial fertilizer. Birkeland's climactic reply was "I have it." He worked long enough to build a (the Birkeland–Eyde) plasma-arc device for the first industrial nitrogen-fixation process. Thus, the Birkeland fixation method was the founding of Norsk Hydro, still today a major industrial enterprise, and one of Norway's largest companies. Birkeland then enjoyed adequate funding for his only real interest, basic research.

Birkeland continued with industrial inventions and had altogether 60 different patents. Today, Birkeland's plasma torches find application in the steel industry, tool hardening, and nitrification of radioactive waste.

In his last years, Birkeland's main scientific work was an extension of his theory on aurorae and geomagnetic disturbances to a more general theory of the cosmos. He concluded, in 1908, that charged particles are continuously emitted from the Sun and that electromagnetic forces are as important as gravity in the Universe.

Birkeland based most of his ideas on models from the results of laboratory experiments. He contributed greatly to the study of solar-terrestrial physics. He introduced many ideas that still remain central to these fields. His work was truly the foundation for modern space physics.

In the field of basic physics Birkeland had nearly 70 publications plus three books. His main contribution remains *The Norwegian Aurora Polaris Expedition 1902–1903*. It was published in two volumes in 1908 and 1913, respectively, and is nearly 850 pages long. It is still a good reference book for solar-terrestrial physics.

Birkeland's pioneering work underlies many of our present ideas concerning the three-dimensional nature of the Earth's magnetosphere, the workings of polar geomagnetic activity, the aurora, and the connection of the Sun to the magnetosphere. His students included additional auroral observers and theorists Lars Vegard, Ole Andreas Krogness, and Olaf Devik, as well as professors of mathematics (Thoralf Sklem) and physics (Sem Saeland) at the University of Oslo. The Norwegian government (in 1994) honored its most famous scientist with a 200 kr banknote (equivalent to approximately US $30) bearing Birkeland's likeness.

Alv Egeland

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Birkhoff, George David

Born **Overisel, Michigan, USA, 21 March 1884**
Died **Cambridge, Massachusetts, USA, 12 November 1944**

American mathematician George Birkhoff developed two theorems with astronomical applications, one (the ergodic theorem) relevant to systems where one wants to take averages over time and space, and one (Birkhoff's theorem) showing that some results of Newtonian gravitation also apply to general relativistic models of the Universe under certain circumstances. He was the son of David Birkhoff, a doctor, and Jane Gertrude Droppers. At the age of 12, Birkhoff entered the Lewis Institute, a West Side Chicago liberal arts and sciences college that merged in 1940 with the Armour Institute to become what is now the Illinois Institute of Technology. In 1901, a year before his graduation from Lewis Institute, he began a correspondence with mathematician Harry Vandiver on number theory that would lead to his first publication in 1904.

Upon graduation from Lewis Institute, Birkhoff entered the University of Chicago, spending only a year there before transferring to Harvard in 1903. He received an A.B. in 1905 and an A.M. in 1906, both in mathematics. Birkhoff returned to the University of Chicago in 1906 to study for his doctorate. His doctoral thesis, which was purely mathematical in nature, was submitted in 1907 under the title *Asymptotic Properties of Certain Ordinary Differential Equations with Applications to Boundary Value and Expansion Problems*. It was also in this year that Birkhoff accepted a post as a lecturer at the University of Wisconsin at Madison. It was in Madison where he married Margaret Elizabeth Grafius in 1908. The couple had three children including son Garrett Birkhoff, a well-known mathematician. In 1909, Birkhoff accepted the post of preceptor of mathematics at Princeton where he became a professor in 1911. However, in 1912, Birkhoff moved again, this time back to his *alma mater*, Harvard, where he became a full professor in 1919 and where he remained for the rest of his life. Also in 1919, he served as vice president of the American Mathematical Society [AMS]. In 1923, the AMS awarded Birkhoff the first Bôcher Memorial Prize, and he served as president in 1925 and 1926. In 1932, Birkhoff was given the post of Perkins Professor, and in 1936 he became the Dean of the Faculty of Arts and Sciences.

There is a crater on the Moon named after Birkhoff; his other awards and honors are too numerous to name. However, he had one serious character flaw that had a significant effect on his relations with other scientists of his day: Birkhoff was unabashedly anti-Semitic. Some of his actions included hindering the appointment of Jews to posts at Harvard and making openly anti-Semitic remarks in his correspondence. During the 1930s and 1940s Birkhoff did help a few European refugees get jobs, though none at Harvard.

Birkhoff was primarily a mathematician, but several aspects of his work were to become useful in astrophysics. **Jules Poincaré** was considered Birkhoff's greatest influence, though it was purely from Birkhoff's intense reading of Poincaré's work that this influence was gained. In 1913, Birkhoff proved Poincaré's last geometric theorem, which is a special case of the 3-body problem. His main body of work was on dynamics and ergodic theory. In fact he developed the ergodic theorem that turned the Maxwell–Boltzmann kinetic theory of gases into a rigorous principle using a process known as Lebesgue measure. Ergodic theory has been applied to numerous astrophysical processes including orbital mechanics, stellar dynamics, gravitation, the propagation of photons in the solar corona, and relativistic cosmology.

Within astrophysics, Birkhoff was perhaps best known for what is now referred to as Birkoff's theorem. In 1923, he proved generally that there is a unique solution to **Albert Einstein**'s field equations for a spherically symmetric distribution of matter. One way of writing this solution is:

$$(d^2R)/(dt^2) = -(4/3)\pi G\rho R(t)\,,$$

where $R(t)$ represents a dimensionless factor that describes an expansion, in this case, of the Universe. This equation describes the acceleration of a mass shell in the Universe and shows that it is dependent only on ρ and R. Birkhoff's theorem holds even when general relativity is included making it a vital component in the study of cosmology. It was, for example, an important starting point for **Georges Lemaître** in the evolution of his primeval-atom hypothesis.

Ian T. Durham

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Birmingham, John

Born **probably Milltown near Tuam, Co. Galway, Ireland, May 1816**
Died **Milltown, Co. Galway, Ireland, 8 September 1884**

John Birmingham was a talented amateur astronomer and polymath who is noted for his discovery of the recurrent nova T Coronae Borealis in 1866 and for his systematic study of red stars, which culminated in the publication of his *Red Star Catalogue* by the Royal Irish Academy in 1877.

Birmingham was the only child of Edward Birmingham and Elly Bell of Millbrook House, Milltown. The Birminghams were descended from the Anglo–Norman family of De Bermingham, barons of Athenry, who owned large estates in Connaught until their confiscation in the 17th century. Land restorations by Charles II included the granting of an estate near Milltown, 200 acres of which were inherited by Major John Birmingham, grandfather of the astronomer.

John Birmingham was educated at Saint Jarlath's College in Tuam and also received private tuition in Latin at home. In 1832, at the age of 16, he was apprenticed to Richard Jennings, a neighboring solicitor. Little else is known about his education except that he is reputed to have spent 6 or 7 years studying in Berlin. During that time he traveled widely in Europe and became competent in several languages.

By 1854, Birmingham was residing in Millbrook House and, apart from his duties as landlord, was studying the geology of the surrounding countryside. Although no portrait of him exists, he was said to have been tall and well built, and his athletic prowess earned him the sobriquet "The Big Fellow." It is not difficult to imagine him striding over the east Galway landscape searching for fossils and mineral specimens. Richard Griffith, the distinguished Irish geologist, encouraged Birmingham to survey the glacial deposits of Galway Bay and southeast Mayo. This work resulted in his first scientific paper, presented at the Dublin meeting of the British Association for the Advancement of Science in 1857. More detailed presentations of his work were given to the Geological Society of Dublin in 1858 and 1859 and gave rise to a vigorous discussion between the leading experts of the time.

Birmingham's well-informed letters and articles on comets that appeared in *The Tuam Herald* between 1859 and 1861 attest to his keen interest in astronomy. However, his astronomical talents came to a much wider notice in 1866:

> On my way home from a friend's house, on the night of May 12, I was struck with the appearance of a new star in *Corona Borealis* . . . . Its colour appeared to me nearly white, with a bluish tinge; and, during the two hours that I continued to observe it, I detected no change in its light or in its magnitude . . . . I regret to say that my instrumental means of observation were limited to an ordinary telescope with a power of about 25. [*Monthly Notices of the Royal Astronomical Soceity*, 26(1866): 310.]

Birmingham immediately wrote a letter to *The Times* of London, but it was ignored, so he wrote directly to **William Huggins** at Tulse Hill. Huggins confirmed the nova and examined its spectra, which indicated that the star was surrounded by a shell of hydrogen. This nova was the brightest since that of 1604 and the first to be identified with an existing star; it had been listed at magnitude 9.5 in the *Bonner Durchmusterung* (Bonn survey), and by early June it had returned to ninth magnitude. A subsequent outburst occurred in 1946 with smaller ones in 1963 and 1975.

Birmingham soon purchased a 4½-in. Cooke refractor on an equatorial mount. It was set up inside a large wooden house with a sliding roof beside Millbrook House. Using a regular magnifying power of 53× he was able to observe down to 12th magnitude. Using this telescope, Birmingham made a special study of red stars. In 1872, the Reverend **Thomas Webb** suggested that Birmingham should revise and update **Hans Schjellerup**'s renowned *Red Star Catalogue*. Birmingham's catalog of 658 stars, with numerous spectroscopic observations, was presented to the Royal Irish Academy on 26 June 1876 and published the following year. On 14 January 1884, the Academy awarded him its highest scientific award, the Cunningham Gold Medal, for his outstanding research.

In 1866, **Johann Schmidt**, the director of Athens Observatory claimed that he had observed an obscuration of the lunar crater Linné, implying an explosive volcanic event on the Moon. This claim caused Birmingham to write an article "A Crater on the Moon" for the journal Good Works for Young People. Although Schmidt's claim was later discounted, the article is a cogent and well-argued commentary on the current theories of lunar craters, and it demonstrates Birmingham's scientific integrity and ability to write clearly. He corresponded with Schmidt, **Angelo Secchi**, Webb, and others on lunar matters, and the naming for him of a feature in Mare Frigoris recognized Birmingham's contributions. This designation was later changed to a 92 km-diameter crater at 65°.1 N, 10°.5 W, to the south of Anaxagoras.

Apart from red stars and the Moon, Birmingham's astronomical interests covered a wide range of other topics including comets, meteor showers, sunspots, occultations, and some of the planets. These findings were published mainly in *Monthly Notices of the Royal Astronomical Society*, *Astronomische Nachrichten*, and *Nature*. His last astronomical paper was an account of his observations of the transit of Venus across the Sun's disk on 8 December 1882.

In the course of his work Birmingham corresponded with many astronomers. They included the renowned stellar spectroscopist Secchi at Rome, Schjellerup and **Heinrich d'Arrest** at Copenhagen, Schmidt at Athens, Walter Doberck at Markree, County Sligo, Huggins at Tulse Hill, London, **Robert Ball** at Dunsink, and many others.

Apart from his scientific work, Birmingham was accomplished in many other ways. As a gifted poet he often turned to verse to express his thoughts. He had a keen ear and played the violin and piano very well. He was a devout Roman Catholic, noted for his modesty and compassion and was loved and respected by his tenants and neighbors.

Birmingham died from an attack of jaundice on the morning of 8 September 1884. As he never married, all his possessions were auctioned. His telescope was purchased for Saint Jarlath's College in Tuam where it still remains. His 700-volume library and Cremona violin were among other items sold. Millbrook House became an isolated and roofless ruin, and the big trees around it were felled in the 1940s.

At the time of his death, Birmingham was a local inspector of applications for loans under the Land Law (Ireland) Act and an inspector of the Board of Works. These duties must have weighed heavily on him, as he was also engaged in a revision of his 1877 catalog. The second edition was eventually completed by the Reverend **Thomas Espin** in 1888 and became a standard reference. In spite of his isolation, John Birmingham achieved much.

Ian Elliott

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Birt, William Radcliff

Born **Southwark, (London), England, 15 July 1804**
Died **Leytonstone, (London), England, 14 December 1881**

William Birt is considered one of the leading selenographers during the 1860s and 1870s and contributed greatly to contemporary understanding of the surface of the Moon. He also studied sunspots and the solar rotation. Birt founded the Selenographical Society and *Selenographical Journal* in 1878. A crater on the Moon bears his name. Birt's work with **John Herschel** influenced the search for a meteorological model of the Earth.

Birt's first published astronomical articles were on the periodical variations in the brightness of β Lyrae and α Cassiopeiae in the *Monthly Notices of the Royal Astronomical Society*. While living near Bethnal Green in London, Birt made an observational evaluation of a celestial map produced by the Astronomical Society (now the Royal Astronomical Society) for the *Diffusion of Useful Knowledge during 1831 and 1832*. He communicated a dozen corrections for the celestial map to John William Lubbock, and further proposed a Milky Way survey project.

As a result of Birt's early astronomical work, he came to the attention of John Herschel, who liked Birt's mathematical thoroughness. Herschel employed Birt in making and analyzing meteorological measurements. Between 1839 and 1843 Birt acted as Herschel's "computer," compiling, arranging, and reducing many series of barometric measurements. The intent of this effort is well illustrated in a July 1843 letter Herschel wrote to Birt hypothesizing that the atmosphere might be considered "a vehicle for wave-like movement which may embrace in their single swell & fall a whole quadrant of a globe."

In the early 1840s, Herschel proposed to the British Association for the Advancement of Science that Birt be appointed as the director of the new project to discover laws of weather behavior. Birt enthusiastically accepted the offer. Birt's first publication was a report to the British Association sharing a summary of Wilhelm Dove's account of "Arial Currents in the Temperate Zone." He also wrote on the popular topic of cloud formation in Louden's *Natural History Journal*. After five reports for the British Association and several contributions to the *Philosophical Magazine*, however, Birt dropped the research in 1849 without a conclusive explanation of midlatitude atmospheric disturbances. He declared that the 6-year effort was less than rewarding. Birt's last meteorological work was the *Handbook of the Law of Storms* (1853), a digest of the storm research meant to help with the navigation of ships. The *Handbook* was found useful by ship captains in avoiding storms; a second edition was published in 1879.

Birt then returned to astronomy, his first scientific love. He built his own private observatory in 1866 and also spent many nights observing with his colleague, Dr. John Lee at the latter's Hartwell Observatory.

It was during the late 1860s and 1870s that Birt's research reached its greatest productivity. In addition to founding the Selenographic Society, he was deeply involved in attempting to detect the exciting transient lunar phenomena then being reported frequently, particularly in the craters Geminus, Linné, and Plato. In May 1870, it was Birt's opinion that the lights around the crater Plato were not from the effects of sunlight. "There was an extraordinary display" on 13 May according to Birt. By April of 1871, selenographers had recorded over 1,600 observations of the fluctuations of the lights in Plato, and had drawn 37 graphs of individual lights. (All these observations and graphs are in the archives of the Royal Astronomical Society.) Birt was among those in the astronomical community who leaned strongly toward the hypothesis that volcanic eruptions still took place on the Moon from time to time. The lights in the floor of Plato were considered strong possible evidence in support of that hypothesis. Also in support of that hypothesis, Birt published an article in the *Student and Intellectual Observer* in 1868 entitled: "Has the surface of the Moon attained its final condition?"

Birt's major selenographical contribution, however, was in an effort to upgrade the best lunar map then available, that of **Wilhelm Beer** and **Johann von Mädler**. Birt found at least 368 craters on the Moon's surface, many of which were very small, that had not been cataloged by Beer and Mädler. Birt organized a committee on mapping the surface of the Moon, the membership of which included John Phillips, Sir John Herschel, **Warren De La Rue**, **William Parsons** (Lord Rosse), and **Thomas Webb**. The committee's goal was to map the Moon's surface at a scale of 200 in. to the diameter of the Moon. This was an ambitious project compared to the 37.5-in.-map of Beer and Mädler. As secretary of the committee, Birt published five reports on the committee's progress in the *Proceedings of The British Association for the Advancement of Science*.

Robert McGown

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Bīrūnī: Abū al-Rayḥān Muḥammad ibn Aḥmad al-Bīrūnī

Born **4 September 973**
Died **possibly Ghazna (Afghanistan), *circa* 1050**

Bīrūnī was one of the most accomplished scientists of the entire Middle Ages, and his interests extended to almost all branches of science. The total number of his works, mostly in Arabic, is 146, of which only 22 are extant. Approximately half of these writings are in the exact sciences. In addition to mathematics, astronomy, and astrology, he was accomplished in the fields of chronology, geography, pharmacology, and meteorology.

Bīrūnī was born in the "outskirts" (*bīrūn*) of Kāth, a city in the district of ancient Khwārizm, which is located south of the Aral Sea. At the beginning of his career, he worked for the Sāmānid ruler Manṣūr II, but due to political turmoil he had to change his patrons frequently. Eventually, he was captured as a political prisoner by the Ghaznawid Sultan Maḥmūd and was taken to Ghazna, where he remained until his death.

In his youth, Bīrūnī studied Greek science, especially astronomy. He was convinced of the importance of observation, and he recorded many of his own observations in his books. One of these works is his *Taḥdīd al-amākin* (Determination of coordinates of cities), which he wrote as a prisoner on his journey in 1018 from Khwārizm to Ghazna. In this book, Bīrūnī mentions a lunar eclipse of 997 that he observed in Khwārizm, having arranged a simultaneous observation with **Abū al-Wafāʾ al-Būzjānī** who was residing in Baghdad. Bīrūnī's aim was to find the difference in longitude of the two cities.

Bīrūnī's *The Chronology of the Ancient Nations*, written in about 1000, is a mine of information on calendars used by the Persians, Sogdians, Kwārizmians, Jews, Syrians, Ḥarrānians, Arabs, and Greeks. This is still one of the most reliable sources on ancient and medieval chronology. Bīrūnī does not mention much about India, because at this time he was not yet well informed about the Indian calendar.

In the second half of his life, Bīrūnī became more and more interested in Indian culture. This change may have been the result of his accompanying Sultan Mahmūd on several expeditions to India. By virtue of Bīrūnī's service as an interrogator of Indian prisoners, among whom were learned scholars, he was able to accumulate much knowledge of Indian culture, especially that of the exact sciences written in Sanskrit. His studies on India resulted in his masterpiece called *India*, completed in 1030. With this book, Bīrūnī well deserves to be called "the first Indologist" in the modern sense of the word.

One may characterize Bīrūnī's attitude toward Indian culture as a mixture of sympathy and criticism; on the whole, he was fair and without prejudice. Because he was well acquainted with Greek science, Bīrūnī was able to compare Greek and Indian astronomy and make evaluative comments. The Indian astronomer whom he referred to most frequently was **Brahmagupta**. He even stated that he intended to translate Brahmagupta's *Brāhmasphuṭasiddhānta* into Arabic; however, since he was unable to complete it, he instead provided a table of contents.

Bīrūnī was most productive in the years around 1030, after Maḥmūd died and the throne passed on to his elder son Masʿūd, to whom Bīrūnī dedicated his *magnum opus* on astronomy, *al-Qānūn al-Masʿūdī*. The book consists of 11 treatises (*maqāla*s), each containing several chapters (*bāb*s); some chapters are further subdivided into sections (*faṣl*s). Treatise I is an introduction, dealing with the principles and basic concepts of astronomy as well as cosmology, time, and space. Treatise II deals with calendars, the three best known being the Hijra, Greek (*i. e.*, Seleucid), and Persian. Treatise III is on trigonometry. Treatise IV takes up spherical astronomy. Treatise V discusses geodesy and mathematical geography. Treatise VI is on time differences, the solar motion, and the equation of time. Treatise VII deals with the lunar motion. Treatise VIII is on eclipses and crescent visibility. Treatise IX is on the fixed stars. Treatise X is on the planets. Treatise XI describes astrological operations.

Al-Qānūn al-Masʿūdī is primarily based on **Ptolemy**'s *Almagest*, but many new elements, of Indian, Iranian, and Arabic origin, are added. Bīrūnī also tried to improve Ptolemy's astronomical parameters using the observations that were made by his predecessors and by himself. He refers to the elements of Indian calendar and chronology in Treatises I and II. In Treatise III, after explaining the chords according to Ptolemy, he offers a table of sines as well as a table of tangents (gnomon shadows). The 1,029 fixed stars are tabulated in Table IX.5.2 following the model of those in the *Almagest* (where the number is 1,022). To the longitude of the stars in the *Almagest*, Bīrūnī added 13° according to the increase from Ptolemy's time due to the precession of equinoxes. The magnitudes of the stars are given in two columns, one based on the *Almagest* and the other from **Ṣūfī**'s book on 48 constellations. Bīrūnī's planetary theory, which is found in Treatise X, is essentially the same as Ptolemy's, with some modifications in the parameters. The last treatise is on the topic of astrology, which require highly advanced knowledge of mathematics; these include the equalization of the houses and the determination of the length of one's life by means of the computation of an arc called *tasyīr*.

Although *al-Qānūn al-Masʿūdī* did not have much influence in medieval Europe, the book was well read in the eastern half of the Muslim world and indeed further east. One example of this is that a very peculiar irregularity in Mercury's first equation table in the *al-Qānūn* can be attested to in the Chinese text *Huihui li* (composed in 1384).

Another major work of Bīrūnī is on astrology: *Kitāb al-tafhīm li-awāʾil ṣināʿat al-tanjīm*. The Arabic manuscript in the British Museum was published with an English translation by R. R. Wright. The translation, however, was made from a Persian version. This book is divided into three parts with the subject areas being mathematics, astronomy, and astrology. Bīrūnī's aim is very clearly stated by himself: "I have begun with geometry and proceeded to arithmetic and the science of numbers, then to the structure of the Universe, and finally to judicial astrology, for no one is worthy of the style and title of astrologer who is not thoroughly conversant with these four sciences."

It is undoubtedly because Bīrūnī and his work were not well known to medieval Europeans that his Latinized name survives in a modern French dictionary as "aliboron," which means "stupid person" – clearly an inept description for this Islamic medieval polymath whose passion for knowledge was reflected in the scope and areas of interest he pursued.

Michio Yano

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Biṭrūjī: Nūr al-Dīn Abū Isḥāq [Abū Jaʿfar]Ibrāhīm ibn Yūsuf al-Biṭrūjī

Flourished **Andalusia (Spain), 1185–1192**

Biṭrūjī was a famous Andalusian (Arab) cosmologist who wrote an astronomical work that was quite influential in Latin Europe, where he was known as Alpetragius. Little is known of his life. He was probably a disciple of the philosopher **Ibn Ṭufayl** (died: 1185/1186), who was already dead when Biṭrūjī wrote his *Kitāb fī al-hay'a*. On the other hand, an anonymous treatise on tides (Escorial MS 1636, dated 1192) contains ideas seemingly borrowed from Biṭrūjī's work. A more definitive guide to dating is **Michael Scot**, who finished his Latin translation of Biṭrūjī's work in Toledo in 1217. His book was also translated into Hebrew by Mosheh ben Tibbon in 1259, and one of the manuscripts of this Hebrew translation states that he was a judge. A late 15th-century Moroccan source calls him *faqīh* (jurist). His name, al-Biṭrūjī, may be a corruption of al-Biṭrawshī, derived from Biṭrawsh, a village in Faḥṣ al-Ballūṭ (Cordova province).

Biṭrūjī's only extant work bears the title *Kitāb [murtaʿish] fī al-hay'a* (A [revolutionary] book on cosmology), which is extant in two Arabic manuscripts, the Latin translation of Scot, the Hebrew translation of ben Tibbon, and the Latin by Calo Calonymos (1286–*circa* 1328) from the Hebrew. A modern English translation and commentary can be found in Goldstein (1971).

Biṭrūjī's book is the final result of the efforts made by Andalusian Aristotelian philosophers of the 12th century (**Ibn Bājja**, **Ibn Ṭufayl**, **Ibn Rushd**, and **Maimonides**) to overcome the physical difficulties inherent in the geometrical models of **Ptolemy**'s *Almagest* and to describe the cosmos in agreement with Aristotelian or Neoplatonic physics. It is a book on *hay'a* (theoretical astronomy/cosmology). Earlier Andalusian work in this genre include two books by **Qāsim ibn Muṭarrif al-Qaṭṭān** (10th century), who followed the line of Ptolemy's *Planetary Hypotheses*, and an anonymous Toledan author of the second half of the 11th century who seems to represent the earliest Andalusian attempt to criticize the *Almagest* from a physical point of view. Despite these precedents in the Islamic west, Biṭrūjī seems to be the first to present alternatives to Ptolemy's models. His knowledge of the astronomical literature, though, was limited; he had probably read the *Almagest*, but he does not seem to have understood it completely. According to Biṭrūjī, Ptolemy was the archetypical mathematical astronomer who created imaginary models that were successful in their ability to predict planetary positions but were totally unreal.

Besides Ptolemy, Biṭrūjī may have read **Theon of Alexandria**'s *Commentary to the Almagest.* He also was well acquainted with the treatise on the motion of the fixed stars by **Zarqālī**. Furthermore, he quotes **Jābir ibn Aflaḥ**'s *Iṣlāḥ al-Majisṭī* (Revision of the *Almagest*) regarding the problem of the order of the planets in the Solar System but rejects Jābir's proposal to put both Mercury and Venus above the Sun, opting instead to make only Venus a superior planet. Jābir had argued that proposal on the basis of a lack of records of Mercury or Venus transits, but Biṭrūjī suggested that this might be because of both Mercury and Venus being self-luminous.

Biṭrūjī presented the first non-Ptolemaic astronomical system after Ptolemy, although he admits that the results are only qualitative. As a follower of **Aristotle**, his system is homocentric, the celestial bodies being always kept at the same distance from the center of the Earth. Despite this, Biṭrūjī employs mathematical eccentrics and epicycles, which are placed on the surface of the corresponding sphere and in the area of the pole. Apparently, he has adapted ideas derived from Zarqālī's trepidation models or perhaps from **Eudoxus**.

One of the most original aspects of Biṭrūjī's system is his proposal of a physical cause of celestial motions. Biṭrūjī uses the idea of *impetus*, originally put forth by **John Philoponus** (6th century) to deal with forced motion in the sublunar world, to account for the transmission of energy from a first mover that is placed in the ninth sphere. The motion of the ninth sphere, which rotates uniformly once every 24 hours, is transmitted to the inner spheres, and it becomes progressively slower as it approaches the Earth. The velocity of rotation of each sphere is used by Biṭrūjī to establish the order of the planets. It is noteworthy that Biṭrūjī is applying the same dynamics to the sublunar and the celestial worlds, contradicting the Aristotelian idea that there is a specific kind of dynamics for each world. Indeed, the force of the first mover reaches the sublunary world causing the rotation of comets in the upper atmosphere as well as the tides. Similar ideas can also be found in Ibn Rushd. Both Ibn Rushd and Biṭrūjī use another idea to explain this transmission of motion: the celestial spheres feel a "passion" or "desire" (*shawq*, *desiderium*) to imitate the sphere of the first mover, which is the most perfect one. Thus the spheres closer to the first mover are most like the ninth sphere and therefore move faster, while those farther away move slower. This use of *shawq* seems to derive from Neoplatonic notions developed by the philosopher Abū al-Barakāt al-Baghdādī (died: 1164), whose ideas may have been introduced into Andalusia by his disciple Abū Saʿd Isaac, the son of **Abraham ibn ʿEzra**.

Impetus and *shawq* were used by Biṭrūjī in his attempt to solve a puzzling problem: How can one explain that the unique first mover can produce both the daily east–west motion and the longitudinal (zodiacal) west–east motions in the planetary spheres? Biṭrūjī's explanation is that the motions in longitude can be explained as a "delay" (*taqṣīr*, *incurtatio*) in the perfect daily motion being transmitted by the first mover; this delay becomes progressively more noticeable in the planetary spheres further away from the first mover.

Biṭrūjī builds his geometrical models on this theoretical basis. *Taqṣīr* corresponds to the planetary motion in longitude while Biṭrūjī seems to identify *shawq* with the anomaly. In the case of the planets, each one of them moves near the ecliptic but its motion is regulated by the pole of each planet, placed at a distance of 90° from the planet itself. This pole rotates on a small polar epicycle whose center moves, as a result of *taqṣīr*, on a polar deferent. This use of a type of deferent and epicycle (within the context of homocentric astronomy) allows Biṭrūjī to explain, in a way similar to Ptolemy, the irregularities of planetary motions (direct motion, station, retrogradation). The problem is that Biṭrūjī also tries to explain, using the motion in anomaly (rotation of the pole of the planet on the polar epicycle), the changes in planetary latitude. This, however, does not really work since the periods of recurrence in anomaly and in latitude are not the same. Other problems result due to Biṭrūjī's ambiguity regarding the direction of motions and the fact that *shawq* does not diminish, as claimed, in the planetary spheres as they are further removed from the first mover. Thus, despite their ingenuity, Biṭrūjī's models are unable to provide the predictive accuracy of Ptolemy's models, and there are inconsistent aspects to them as well. In the case of the fixed stars, he proposes a model that results in a variable velocity in the precession of equinoxes, which echoes earlier Andalusian theories of the trepidation of the equinoxes. The geometrical model for the fixed stars is not easy to understand as preserved in the extant texts. A recent paper by J. L. Mancha (2004) gives a new and sophisticated interpretation, based on the Latin translation, which supports the hypothesis formulated by E. Kennedy in 1973 that Biṭrūjī's homocentric system is an updating and reformulation of the system of Eudoxus. For the motion of the fixed stars the Zarqālian tradition would be combined with aspects of Eudoxus's models, *i. e.*, he uses a Eudoxan couple that results in a hippopede. With Mancha's interpretation, Biṭrūjī's model for the fixed stars makes sense, but we have the problem of establishing which sources available to the Andalusian cosmologist gave him information on Eudoxus's models.

Despite its scientific failings, the *Kitāb fī al-hay'a* was quite successful. The Latin translation by Michael Scot contributed to its European diffusion between the 13th and the 16th centuries. It was accepted in scholastic circles where it was considered a valid alternative to Ptolemy's *Almagest*. The work was also known in the Islamic East, perhaps introduced in Egypt by Maimonides. The Damascene astronomer **Ibn al-Shāṭir** mentions a certain al-Majrīṭī as having presented non-Ptolemaic models; this may be a corruption of al-Biṭrūjī's name.

Julio Samsó

Alternate name

Alpetragius

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Bjerknes, Vilhelm Frimann Koren

Born **Christiana (Oslo, Norway), 14 March 1862**
Died **Oslo, Norway, 9 April 1951**

Norwegian mathematical physicist and geophysicist Vilhelm Bjerknes is best remembered for his work in meteorology, which, however, had considerable impact on planetary astronomy and the study of the atmospheres of other planets.

Bjerknes' father was Carl Bjerknes, the noted hydrodynamicist who studied under Dirichlet in Paris. His mother was Aletta Koren. Vilhelm was born in what is now Oslo but was then Christiana. (It was renamed Kristiana in 1877 and then Oslo in 1925.) He began undergraduate studies in 1880 at the University of Kristiana and was awarded a Master's degree from there in 1888. All through this period he had collaborated with his father on hydrodynamical research, but, as his father became more reclusive in his later years, Vilhelm ended the collaboration after he received his Master's degree. He was awarded a state scholarship that allowed him to travel to Paris in 1889 where he attended lectures by **Jules Poincaré** on electrodynamics.

From 1890 to 1892, Bjerknes worked as an assistant to Heinrich Hertz in Bonn. Later in 1892, he returned to Norway to complete his doctoral thesis based on the work he had performed with Hertz in Bonn on electrical resistance in narrow frequency bands (something that would later become useful in the development of the radio). With his degree in hand, Bjerknes was given a lectureship at the Högskola (School of engineering) in Stockholm in 1893. Two years later he became professor of applied mechanics and mathematical physics at the University of Stockholm.

On 2 November 1897, Bjerknes' wife gave birth to their son Jacob who would later become famous for discovering the mechanism that controls cyclones. A trip to the United States in 1905 began 36 continuous years of funding from the Carnegie Foundation.

In 1907, Bjerknes returned to Kristiana to take up the post of chair of applied mechanics and mathematical physics. He was not to stay there for long, however. Just 5 years later the University of Leipzig offered him the chair of geophysics. He accepted this offer and took a number of his Kristiana collaborators with him, including his son Jacob, then aged 15. This post was followed in 1917 with an appointment as chair at the University of Bergen where he founded the Bergen Geophysical Institute. Nine years later he made his final move, returning once again to his *alma mater*, then known as the University of Oslo, to take up the chair he left in 1912. Bjerknes retired in 1932.

Most of Bjerknes' career was based on hydrodynamics in one form or another. He also was the first person to suggest that sunspots were the erupting ends of magnetic vortices that were caused by the Sun's differential rotation. His work in meteorology produced a number of commonly known terms such as "cold front," "warm front," and "stationary front." He is considered to be the father of modern numerical weather prediction. Bjerknes' equations (and those produced by his assistants at Bergen) for vortices, which he originally derived from the vortex work of **William Thomson** (Lord Kelvin) and **Hermann von Helmholtz**, are so rigorous that modern computers still have difficulty solving them in reasonable timescales.

Ian T. Durham

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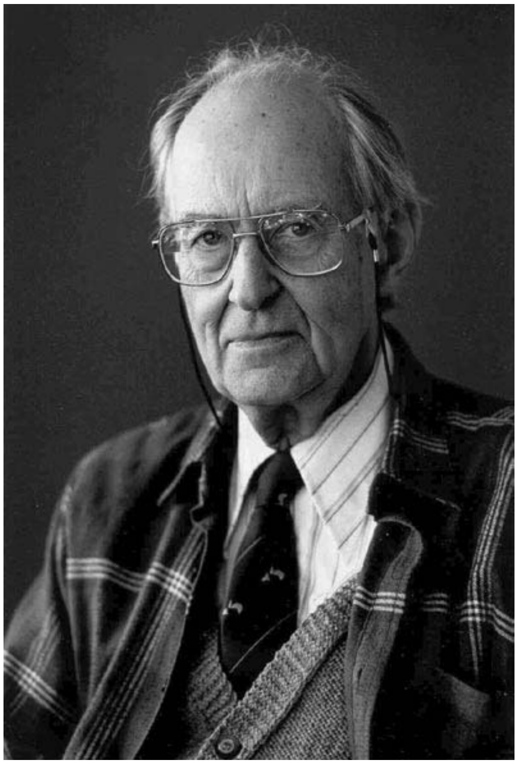
Blaauw, Adriaan

Born **Amsterdam, the Netherlands, 12 April 1914**



Among many accomplishments, Blaauw is credited with two important ideas in the field of stellar dynamics: First, many clusters of hot, bright stars are unstable and currently dissipating, and so must be very young; second, hot, massive stars with large velocities relative to the disk of the galaxy (runaway stars) might be former members of binary systems whose companions exploded as supernovae, leaving them to move off in a straight line at the speeds they formerly had as orbital speeds. Both contributed to the establishment within astronomy of the principle that star formation is an ongoing process, at a time when this was not widely understood.

Blaauw, the son of Cornelis Blaauw and Gesina Clasina Zwart, received his early education in Amsterdam, his bachelor's and master's degrees from the University of Leiden, and, in 1946, a Ph.D. (*cum laude*) from the University of Groningen. The latter was awarded for work on motions of stars in the Scorpio–Centaurus cluster with **Pieter van Rhijn**. Blaauw's major professional positions have included: assistantship at the Kapteyn Institute (1938–45), lecturer at Leiden (1953/54), associate professor at the University of Chicago (1953–57), professor at the University of Groningen and director of the Kapteyn Institute (1957–69), director general of the European Southern Observatory (1970–74), professor at Leiden (1975–1981), and guest investigator at the University of Groningen (1981–). His contributions to the study of the structure of the Milky Way include the correct location of the center, based on data from radio astronomy as well as stellar motions, and tracing the local galactic rotation, also from combined observations.

Blaauw has been on the forefront of international cooperation in astronomy, as one of the founders of the European Southern Observatory [ESO] and an early director of ESO, as first chair of the board of directors of the journal *Astronomy and Astrophysics* (which united six previously separate publications from four countries), and as President of the International Astronomical Union. While in this office, he shepherded the return of the People's Republic of China to membership without loss of the astronomers from the Republic of China (Taiwan) under the rubric "one nation; two adhering organizations."

Blaauw is the recipient of many honors and awards from organizations in the United States, France, England, Scandinavia, Belgium, and Switzerland, as well as from the Netherlands. He is married to Alida Henderika van Muijlwijk; they have one son and three daughters.

Eugene F. Milone

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Blackett, Patrick Maynard Stuart

Born **London, England, 18 November 1897**
Died **London, England, 13 July 1974**

British experimental physicist Patrick Blackett received the 1948 Nobel Prize in Physics for the discovery among cosmic-ray secondaries of the particle now called the muon, confirmation of the positron (discovered by **Carl Anderson**), and for the instrument development that made these possible. Blackett received his early education at Osborne and Dartmouth Naval Colleges, and was commissioned as a midshipman at the outbreak of World War I, though he had not yet completed his education. He participated in the battles of the Falkland Islands and Jutland, rising to the rank of lieutenant. Blackett had decided by the end of the war to resign his commission and briefly visited the laboratory of James Franck at Göttingen, but the Navy sent him and about 400 other young officers up to Cambridge University for a 6-month course to complete their formal education, and within a few weeks he decided to remain at Cambridge, completing first degrees in mathematics (part I of the *tripos* in 1919) and physics (part II of the *tripos* in natural sciences in 1921).

Ernest Rutherford had then just arrived in Cambridge, and Blackett began work with him on the study of collision processes using a Wilson cloud chamber as a detector, obtaining unambiguous evidence both for the disintegration of atomic nuclei and for the buildup of a heavy nucleus from the lighter ones. G. P. S. (Beppo) Occhialini (a student of Enrico Fermi) then arrived in Cambridge, also for a short visit that extended for many years. Together they modified the cloud-chamber technique to improve by a very large factor its efficiency for detection of cosmic ray particles. Cloud chambers have a very low duty cycle, and the early ones, fired at random, often caught not even one cosmic-ray secondary particle. The improvement was a coincidence counter, above the chamber, which told the gas to expand, cool, and reveal particle tracks only when a particle had been seen coming.

In 1933, Blackett became professor of physics at Birkbeck College, London, where the discovery of the particle with the same charge as an electron, but much larger mass (the muon) occurred. In 1937, he was appointed to the Langworthy Professorship at the University of Manchester, following William L. Bragg. As war approached, Blackett joined the Tizard committee, endorsing the majority report that Britain should develop Watson-Watt's radar for defense against enemy aircraft, and, later, the Maud committee, from which his minority report urged Britain to join with the United States in the development of atomic weapons as was eventually done rather than proceeding alone. He moved quickly through a variety of wartime positions, finally becoming director of Naval Operations Research (1942–1945), supervising work on bombsights, radar, antisubmarine measures, and much else, including convoy sizes (which he concluded should be as large as possible, rather than being limited to 60 vessels at most).

Blackett returned to Manchester in 1945, and implemented a large increase in the size of his department. He encouraged **Bernard Lovell** to set up trailers of ex-military radar equipment at Jodrell Bank, near Manchester, and made radio astronomy one of the subjects to be studied in his department. Later, he helped Lovell with plans for the construction of the 250-ft. steerable paraboloid and helped him through subsequent financial and political difficulties.

In 1947, Blackett suggested that the Earth's magnetic field was a fundamental property of a rotating body, and further suggested that the magnetic fields of rotating bodies (the Earth, the Sun, and the star 78 Virginis, the strong magnetic field of which had just been measured by **Horace Babcock**) were roughly proportional to their angular momenta. A critical test of the idea was the measurement of very weak magnetic fields suitable in rotating laboratory objects, and Blackett was able to show that the suggested relationship was wrong. He then turned to the measurement of very weak magnetic fields in igneous rock (remanent fields) beginning in 1951. These paleomagnetic fields preserve the direction that the rocks had relative to the Earth's magnetic field when they solidified. Blackett's work showed that both the latitude of England and the orientation of the land had changed over the past 100 million years, and so provided some of the early evidence in favor of plate tectonics and continental drift.

Blackett continued work in paleomagnetism as professor of physics at Imperial College, London from 1953, in particular encouraging the work of Keith Runcorn and providing support for a critical conference in London in 1964 in which supporters and opponents of ideas about paleomagneticism and plate tectonics presented their opposing views, and more believers left the conference than had arrived. His own work continued, for instance, to reveal the correlations between ancient climates and ancient latitudes determined from rock magnetic measurement.

Blackett officially retired in 1965, being very soon thereafter elected president of the Royal Society (London) and appointed advisor to the new Ministry of Technology. Blackett received more than 20 honorary degrees and academy fellowships and prizes in addition to the Nobel Prize. He was invested with the British Order of Merit in 1967 and created a Life Peer (as Barson Blackett of Chelsea) in 1969.

Roy H. Garstang

Alternate name

Baron Blackett of Chelsea

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Blagg, Mary Adela

Born **Cheadle, Staffordshire, England, 17 May 1858**
Died **Cheadle, Staffordshire, England, 14 April 1944**

British amateur astronomer, Mary Blagg, is best known for her work on lunar nomenclature and variable stars. The daughter of a solicitor, Charles Blagg, Mary was educated at home and at a private boarding school in London. Finding mathematics intriguing, she borrowed her brother's schoolbooks to teach herself mathematical subjects. Even without a formal background, she became increasingly competent in mathematics and gained skills that prepared her to understand basic astronomy. However, it was not until she was middle aged that she became seriously involved with astronomy. Her interest developed after she attended lectures in Cheadle given by **John Herschel**'s grandson, astronomer Joseph Alfred Hardcastle (1868–1917). These University Extension Lectures encouraged Blagg to ponder the possibility of doing original work in astronomy. Although there is no evidence that Hardcastle convinced Blagg of the need to standardize lunar nomenclature, he did suggest selenography as an interesting field to study.

When she became interested in the nomenclature problem, Blagg found that astronomers had already recognized the need for reform. The state of the subject was chaotic. For example, in some cases the same name denoted different formations, and in others different names were given to the same formation. After **Samuel Saunder** drew its attention to discrepancies, the Royal Astronomical Society became interested in a uniform nomenclature. Saunder involved Professor **Herbert Turner** in the problem. Turner represented the Royal Society before the International Association of Academies in Vienna in 1907. At that meeting, an international Lunar Nomenclature Committee was formed with Saunder as an active participant. Saunder, in turn, asked Blagg to assist him by collating the names given to lunar formations on existing maps of the Moon. In 1913, her *Collated List* was published under the auspices of the International Association of Academies.

The organizational meeting of the International Astronomical Union [IAU] was held in Brussels in 1919. From this date, the IAU has been the arbiter of planetary and satellite nomenclature. Blagg's interest in the Moon continued, and in 1920 she was appointed to the Lunar Commission of the IAU. The other members of the Lunar Commission were **Guillaume Bigourdan**, **Karl H. Müller**, **William Pickering**, and **Pierre Puiseux**, with Turner serving as chair. The Lunar Commission prepared a definitive list of names that, after it was published, became the standard authority on lunar nomenclature. The report of the committee, published as "Named Lunar Formations," was the first systematic listing of lunar nomenclature and named Blagg and Müller as authors.

Blagg also became interested in variable stars through Turner who had acquired a manuscript containing **Joseph Baxendell**'s raw data on variable stars. Turner called for skilled volunteers to assist him in analyzing these data. Blagg volunteered to help, and produced a series of ten papers jointly authored with Turner in the *Monthly Notices of the Royal Astronomical Society* (1912–1918). Turner reported that the task of editing these data fell almost entirely to Blagg. He stressed the difficulties of identification and praised her ability to analyze and interpret the ambiguities. Blagg's experience with Baxendell's data prepared her to study the eclipsing binary β Lyrae and the long period variables RT Cygni, V Cassiopeiae, and U Persei. She deduced new elements for these stars and harmonically analyzed the light curves obtained from the observations of other astronomers.

Mary Blagg was an unassuming woman who never married and who was rarely seen at meetings. It was notable when she attended the IAU meeting at Cambridge in 1925 and even more so when she attended the meeting in Leiden in 1928. She spent much of her time in community service, including caring for Belgian refugee children during World War I. During the last 8 years of her life heart trouble reduced her to an invalid. Like several other British and American women astronomers of her time, Mary Blagg might have become a professional astronomer if the opportunity had presented itself. She managed to succeed in astronomy partially because she was willing to work under the direction of others and to undertake tedious problems rejected by male astronomers. Her skill and good judgment in approaching these problems assured that her contributions were more than mere fact collecting. The Royal Astronomical Society recognized

Blagg's importance and elected her a fellow in 1915. Following her death, the International Lunar Committee assigned the name Blagg to a small lunar crater.

Marilyn Bailey Ogilvie

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Blanchinus, Francisco

➔ **Bianchini, Francesco**

Blazhko, Sergei Nikolaevich

Born **Khotimsk near Mogilev, (Belarus), 17 November 1870**
Died **Moscow, (Russia), 11 February 1956**

Soviet astronomer Sergei N. Blazhko was a noted observer and an acclaimed pedagogue, the author of three prominent textbooks in multiple editions. He was an 1892 graduate of the Moscow University, where he later taught throughout his life, and a disciple and follower of **Vitold Tserasky**. His name is now most often heard in connection with the Blazhko effect, an irregularity in the periods of RR Lyrae stars which is, in turn, periodic. The cause has not yet been firmly established.

After the devastating period following the Bolshevik Revolution of 1917, Blazhko was a key figure within the Moscow University leadership of the Moscow Observatory, founded in 1895 under the directorship of Tserasky. Blazhko held a variety of positions at the Moscow University, including professor of astronomy (1918), deputy director of the Astronomical Observatory (1918–1920), director of the Observatory (1920–1931), chair of the Department of Astronomy (1931–1937), and chair of the Department of Astrometry (1937–1953). Blazhko was an efficient observer and an authoritative expert on positional astronomy (astrometry) and astronomical instruments. A benevolent person and an excellent pedagogue, he had numerous disciples. Blazhko masterminded the conversion of the Moscow Observatory from a modest educational unit into a great scientific institution of worldwide significance (the Shternberg State Astronomical Institute, usually abbreviated as GAISh, or SAI).

Despite the inhumanity of Stalin's regime, Blazhko continued to maintain high moral standards and served as a role model for generations of his followers. Blazhko's contribution to the investigation of different kinds of variable stars helped create a strong Moscow research program. He also enriched the important photographic glass library of the Moscow Observatory. Interested also in history of astronomy, Blazhko compiled a valuable history of a century of astronomy at the Moscow University from 1824 to 1920.

Blazhko's name was not widely recognized in the West apart from his effect, but he was well known to compatriots. He was a corresponding member of the Union of Soviet Socialist Republics Academy of Science (1929). For his textbooks, Blazhko was awarded the highest state trophy, the Stalin Prize (1952), which was later renamed the USSR State Prize. A crater 54 km in diameter on the farside of the Moon (latitude 31°.6 N, longitude 148°.0 W) is named in his honor.

Alexander A. Gurshtein

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Bliss, Nathaniel

Born **Bisley, Gloucestershire, England, 28 November 1700**
Died **London, England, 2 September 1764**

Nathaniel Bliss was a Savilian Professor of Geometry at Oxford and the fourth Astronomer Royal at the Greenwich Observatory. Bliss (named after his father, a Bisley gentleman) received his BA in 1720 and MA in 1723 from Pembroke College, Oxford. After taking holy orders, he became rector of Saint Ebbe's Church in Oxford in 1736. He also married and had a son, John, in 1740. Bliss replaced **Edmond Halley** as Savilian Professor of Geometry upon the latter's death in 1742, and in the same year became a Fellow of the Royal Society.

Soon after his appointment at Oxford, Bliss began a correspondence with **James Bradley**, third Astronomer Royal. The correspondence began with discussion of the Jovian satellites and lasted for 20 years until Bradley's death in 1762. Bliss also frequently visited Bradley at the Greenwich Observatory and even assisted him on several occasions. Bliss also worked for and with George Parker, second Earl of Macclesfield, on various astronomical problems. Macclesfield, a Fellow of the Royal Society from 1722 and its President from 1752 until his death in 1764, was an accomplished astronomer with his own observatory and assistants. In 1744, Bliss sent Macclesfield a letter requesting that he observe a comet from his observatory at Shirburn Castle, while Bliss, at Greenwich Observatory, made his own meridian observations of the comet (C/1743 X1) approaching the Sun. On 6 June 1761, Bliss, following Bradley's instructions, also observed the transit of Venus when Bradley was unable to do so because of his poor health. On the basis of his observations, Bliss calculated the Sun's horizontal parallax to be 10″.3 (the modern figure is 8″.8) and Venus' horizontal parallax as 36″.3. The results were published the following year in the *Philosophical Transactions of the Royal Society*. Bliss also reported to the Royal Society the observations of the same event made in Bologna by Italian astronomer, **Eustachio Zanotti**.

Bliss' appointment as Astronomer Royal in 1762 following Bradley's death lasted until Bliss' own death in 1764, marking the shortest term of any Astronomer Royal. Because of his brief 2-year tenure, Bliss left behind fewer observations and calculations than his predecessors. Moreover, his work at the observatory was occasionally interrupted because he had retained the Savilian Chair and continued teaching, thus splitting his time between Oxford and Greenwich. He seemed to have been more productive in astronomy before he became Astronomer Royal, although he did observe a solar eclipse in 1764, the results of which were published in the *Philosophical Transactions*. Bliss also converted **John Flamsteed**'s Sextant House into a small observatory specially designed to make room for a 40-in. movable quadrant, although the new observatory was completed only after his death.

Bliss had a great interest in improving clocks. During Bliss' tenure at Greenwich, **Nevil Maskelyne** and John Harrison participated in the second historic trial of Harrison's marine chronometer number 4 in the West Indies. Maskelyne returned from this trip in 1764 to succeed Bliss as Astronomer Royal.

After Bliss' death, his widow initiated a continuation of his lectures by organizing a popular lecture of "Electrical Experiments for the Entertainment of Ladies and others" that was delivered at Oxford on 21 May 1765 by **Thomas Hornsby**, successor to Bradley as Savilian Professor of Astronomy. Furthermore, the Board of Longitude regarded Bliss' work on the problem of longitude (made with his assistant, **Charles Green**, who had also served as Bradley's assistant) as important and useful. Since it was considered private property, the Board purchased this work from Bliss' widow and stored it in the Greenwich Observatory. In 1805, Abram Robertson, Savilian Professor of Geometry, appended Bliss and Green's work (including transits of the Sun, planets, and fixed stars over the meridian; meridional distances of the fixed stars from the zenith; and apparent right ascensions of the planets) to the second volume of Bradley's observations – the first volume had been edited by Hornsby in 1798 – entitled *Astronomical observations made at the Royal Observatory at Greenwich from the Year MDCCL to the Year MDCCLXII*.

Voula Saridakis

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Bobrovnikoff, Nicholas Theodore

Born **Markova, Russia, 29 April 1896**
Died **Berkeley, California, USA, 21 March 1988**

Cometary spectroscopist Nicholas Bobrovnikoff, the son of Theodore Basil and Helena (*née* Gavriloff) Bobrovnikoff, graduated from the Kharkov Gymnasium in 1914. As a youth, he had witnessed the appearance of comet 1P/Halley in 1910.

Although wishing to become an astronomer, Bobrovnikoff enrolled as a student (1914–1917) at the Institute of Mining Engineers in Petrograd (now Saint Petersburg), and later studied at the University of Kharkov. He became a junior officer in the Russian Army and joined the White (anti-Bolshevik) Army in 1918. Severely wounded, recovered, and later ill with typhus, Bobrovnikoff was evacuated to Cyprus in 1920. After recuperating, he made his way to Prague, where he won a scholarship to Charles University (now the University of Prague), and resumed his studies of physics, mathematics, and astronomy, graduating in 1924.

Through the efforts of Yerkes Observatory director **Edwin Frost**, Bobrovnikoff was admitted to the graduate program of the University of Chicago in September 1924. For his doctoral dissertation, Bobrovnikoff made a thorough analysis of the behavior of comet Halley and twenty seven other comets, observed as far back as 1908. He concentrated on the molecular bands and lines within the spectra of these comets, and interpreted their varied appearances as due to fluorescence caused by sunlight. Bobrovnikoff also identified some previously unknown spectral features associated with the comets. He was awarded his Ph.D. in 1927.

Bobrovnikoff received a postdoctoral fellowship and spent the next two years at the Lick Observatory, where he had access to large numbers of plates and spectra taken of comet Halley. He borrowed others from the Mount Wilson Observatory. These observations allowed him to correlate the comet's appearance, brightness, and spectral changes over the entire range of its visibility. Bobrovnikoff studied the development of cometary outbursts and argued for a "striking analogy" between their motions and the behaviors of gases seen in solar prominences. Bobrovnikoff had found evidence for what would later be termed the solar wind, whose outward flow bends the path of material expelled from comet nuclei. A National Research Council Fellowship at the University of California at Berkeley (1929/1930) enabled him to prepare his results for publication. Bobrovnikoff's landmark paper appeared in 1931. He became a naturalized citizen in 1930 and married Mildred Gwynne Sharrer; the couple later had three children.

That same year, Bobrovnikoff was appointed an assistant professor at Ohio Wesleyan University, which housed a 69-in. reflector at its Perkins Observatory. There, he concentrated on the spectra of cool M-type stars, which display strong molecular bands.

Bobrovnikoff succeeded **Harlan Stetson** as director of the Perkins Observatory (*circa* 1934–1952). To ease its financial situation, he negotiated an agreement by which its ownership was transferred to the Ohio State University. Bobrovnikoff continued research and teaching until his retirement in 1966. He coauthored a popular book, *Astronomy Before the Telescope* (1984). Bobrovnikoff lived to see comet Halley's return to our skies during 1985/1986.

Jordan D. Marché, II

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Bochart de Saron [Bochart-Saron], Jean-Baptiste-Gaspard

Born **Paris, France, 16 January 1730**
Died **Paris, France, 20 April 1794**

Jean-Baptiste Bochart de Saron was a patron of the sciences, an optician and observer, and a talented mathematician who improved cometary orbit calculations. As Jean-Baptiste Bochart de Saron, father of Jean-Baptiste, died when his son was one, his mother, Marie-Anne Braïer, entrusted him to her brother-in-law, Elie Bochart, Canon of Notre-Dame. Bochart later entered the Jesuit College, Louis le Grand, where he learned the basic elements of letters and sciences. Although he had a great interest in mathematics, especially geometry, he pursued a law career and entered *parlement* on his 18th birthday, later being appointed a judge. He married Angélique-Françoise d'Aguesseau, and they had five children. His wife died in 1780.

Bochart was admitted to the Académie royale des sciences, first as a *surnuméraire* on 5 June 1779, then as an honorary member in 1785. He served as the academy's vice president (elected in 1782 and 1787) and as *president* (elected in 1783 and 1788).

Bochart manufactured a variety of optical parts for telescopes, including a 30-in. speculum mirror instrument, used by **Charles Messier** from 1765. **Jérôme Lalande** claimed that this telescope was among the most efficient available in Paris at the time. Later, Bochart purchased instruments from the best Paris and London manufacturers, among them a 3.5-ft., 4.2-in. achromatic refractor by **John** and **Peter Dollond**. Further, clocks and instruments by Jesse Ramsden and others joined Bochart's collection, one of the finest in Europe, which he lent to his friends Messier, **Pierre Méchain**, **Guillaume Le Gentil de La Galaisière**, **Pierre Le Monnier**, **Jean-Baptiste Delambre**, and A. P. du Séjour.

Bochart carried out a few observations, sometimes with his scientific friends, from his Parisian residences and his country home in Saron (Champagne). He is best remembered for his work on cometary theory. A lifelong friend of Messier, Bochart calculated the orbits of the comets Messier observed. Bochart improved the numerical method to deduce orbits from a few points, a method established by the Jesuit astronomer **Roger Boscovic**. In May 1781, Bochart calculated the orbit of the purported "comet" discovered by **William Herschel**. After unsuccessful attempts to make the observations fit, he assumed an orbit with a radius of 12 AU, greater than any cometary orbit radius, which turned out to be the correct orbit for the planet Uranus, when computed later by **Pierre-Simon de Laplace**. Moreover, Bochart published, at his own expense, Laplace's *Théorie du mouvement elliptique et de la figure de la Terre*.

Bochart was a key participant in the *Carte de France* project. When public funding for the work ended after the Seven Years War, **César Cassini de Thury** encouraged private funding. Cassini approached Bochart to become codirector in the place of **Charles Camus**, when the latter died. Bochart also maintained a chemical laboratory and an engraving machine.

Following the death and retirement of members of the *Parlement de Paris*, Bochart became its first president on 26 January 1789. In October 1790, while he was on a journey to Italy to prevent revolt against the new French authorities, the *Parlement* was dismissed; as a result of the protests of the dismissed members – Bochart included – they were imprisoned and condemned to the guillotine. Bochart was executed on 20 April 1794. Although not a first-rank astronomer, he was a talented, curious, and wealthy man, a generous patron, and host to many of his contemporaries. To them he was a pleasant and modest person, with scientific competence.

Monique Gros

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Bode, Johann Elert

Born **Hamburg, (Germany), 19 January 1747**
Died **Berlin, (Germany), 23 November 1826**

Johann Bode directed the observatory of the Royal Academy of Sciences (Berlin), helped to publicize an important "law" regarding the planets' distances from the Sun, and published an important reference work (the *Astronomisches Jarhbuch*) for more than 50 years. He was the son of Johann Jakob Bode and his wife Anna Margarete (*née* Kruse).

Following a basic education at his father's business school, Bode acquired an astronomical proficiency on his own, putting to good use the encouragement provided by several local citizens. On the strength of his early publications, he was offered an appointment (1772) at Berlin by **Johann Lambert** as calculator for the *Astronomisches Jahrbuch*, to be issued by the Royal Academy of Sciences. Following Lambert's death in 1777, Bode took over as editor of the yearbook. In 1786, he became a full member of the academy (and professor), and in 1787, director of the Royal Observatory. After resigning from this position in 1825, Bode continued as editor of the *Jahrbuch* until his death. His successor in both positions was **Johann Encke**.

After his arrival in Berlin, Bode was a cofounder (in 1773) of Gesellschaft Naturforschender Freunde zu Berlin (Society of Naturalist Friends). Although this learned body exists today, the initial prominence given to astronomy within its framework ended with his death. Bode was thrice married: in 1774 to Johanna Christiane Lange (died: 1782), in 1783 to Sophie Dorothea Lange (died: 1790), and in 1791 to Charlotte Wilhelmine Lehmann. He had eight children from these marriages.

Bode's name today is best remembered for the Titius–Bode law of planetary distances, which, during his lifetime, seemed to be confirmed in a rather spectacular way by the discoveries of Uranus and the asteroids. Bode publicized the mathematical relation first deduced by Wittenberg professor **Johann Titius**, describing the relative spacing of the planets' orbits. Nonetheless, Bode's influence on astronomy went far beyond the contribution to be expected from someone at a relatively minor observatory on the continent. Bode's career marks the transition in astronomy from a "natural history survey of the heavens" to modern, precision astrometry. His numerous activities turn out, in retrospect, to mirror this change of methodology, effort, and priorities.

The Berlin *Astronomisches Jahrbuch*, which began under Lambert's supervision for the year 1776, followed the tradition established by the *Connaissance des temps* (from 1688) and the *Nautical Almanac* (established in 1766). Its final (184th) volume was published for the year 1959. Yet, organization and layout of the early ephemerides and related material look surprisingly modern. From the beginning, the *Jahrbuch* contained a second part designed as "a collection of the most recent observations, news, commentaries and papers." In the absence of any periodicals devoted strictly to astronomical research, the *Jahrbuch* became an important archive journal serving the whole European astronomical community. It retained this function even after Baron **János von Zach**'s founding of the *Monatliche Correspondenz* in 1800. Only with the appearance of **Heinrich Schumacher**'s *Astronomische Nachrichten* (1821) did the need for publication of research papers in the *Jahrbuch* decline; the practice was discontinued by Bode's successor, Encke.

When Bode took over the observatory from his predecessor, **Johann Bernoulli III**, the facilities were in severe disarray. After bringing the instruments into working order and making arrangements for proper time determinations, he put his modest facilities to optimal use. Bode's diligent astrometric observations spanned 4 decades. A major accomplishment was the measurement of several thousand uncataloged star positions plotted for his monumental sky atlas, *Uranographia* (1801). This atlas was the last to follow the tradition of depicting beautifully engraved constellation figures. At the same time, it was the first to include the vast number of double stars, clusters, and nebulae cataloged by **William Herschel**.

In addition to the responsibilities of the Academy (and its observatory) for calendrical matters, Bode's major concern was public time service. He took special care to provide the public with an accurate clock placed on the outer wall of the observatory building. Berlin later became one of the first European capitals to adopt mean solar time as a public standard. The position of the observatory director entailed other tasks related to the academy (and government) on practical matters. Bode calibrated new instruments for the Prussian geodetic service and advised on the acquisition of instruments for the new observatory established at Königsberg in 1811.

Bode likewise advocated the search for a "missing" planet between Mars and Jupiter that was fulfilled by accidental discovery of the first asteroid. Having taken part in preparations for the systematic search, Bode was one of the men first informed by **Giuseppe Piazzi** of the discovery (and subsequent loss) of (1) Ceres. His most significant contribution was the rapid dissemination of this information to the right people, leading to the celebrated orbital calculations performed by **Carl Gauss** and the subsequent recovery of the object by Zach and **Heinrich Olbers**.

Bode's activities as writer, editor, translator, and lecturer also merit special mention. His (nontechnical) *Anleitung zur Kenntniss des gestirnten Himmels* (Introduction to the Knowledge of the Starry Heavens, 1768) remained, with frequent updates, a standard text for a full century. Bode's 1782 German edition of **John Flamsteed**'s *Star Atlas* was aimed at the professional user. His 1780 edition of **Bernard de Fontenelle**'s 1686 *Entretiens* (with his own commentary) passed through several editions. Bode's lectures at the Academy, as well as for learned societies, covered subjects of general interest. His notes on new discoveries were published in the daily newspaper (*Vossische Zeitung*).

Elected already in 1789 to membership in the Royal Society (London), Bode was a member of numerous foreign academies (Saint Petersburg, Stockholm, Göttingen, Copenhagen, Moscow, and Verona). He was awarded an honorary doctorate from the University of Breslau in 1817. A knight of the Prussian Red Eagle Order, on the 50th anniversary of his work with the Berlin Academy (1822), Bode was awarded the Russian Saint Anne Order.

Bode's life and work cover a critical period of transition in the history of science. His most visible contribution to the development of modern astronomy was perhaps his *Jahrbuch*. By compiling and disseminating astronomical news and discoveries, and aiding the emerging cooperation of European astronomers, he laid the groundwork for the activities of his successors, especially Encke. Bode's writings and his lectures served to establish astronomy as a meaningful part of the early metropolitan culture in Berlin.

Wolfgang Kokott

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Boëthius, Anicius Manlius Torquatus Severinus

Born **probably Rome, (Italy), *circa* 480**
Died **in the *ager Calventianus* (near or in present-day Pavia, Italy), 524–526**

As the West lost contact with Byzantium, Boëthius's writings became one of the few surviving links between Western scholars and Hellenistic scholarship. His writings on logic, arithmetic, and music became standard texts and, along with his other writings, were copied and translated all over Europe.

A few decades after Roman Italy had come under Gothic rule, Boëthius was born into the *gens Anicii:* a powerful, wealthy, aristocratic, Catholic family. His father – who had been Prefect of Rome, Praetorian Prefect, and Consul – died when Boëthius was young, so Boëthius was raised by his eminent kinsman Symmachus. Symmachus saw to Boëthius's education in the Greek-patterned *enkuklios paideia*, an "all-encompassing learning." Boëthius's learnedness and natural talent elevated him through the ranks of public office, eventually to consulship under the Ostrogoth Theodoric in 510. Boëthius attained his highest rank, Master of the Offices, in 522, but from this height he fell: Accused of treason, he was impoverished and imprisoned near Pavia. He remained there while his trial proceeded at Rome. Boëthius, though absent, was found guilty. Boëthius's epitaph records imply that he died by the sword, but the *Chronica Theodoriciana* records an end more painful: Torturers tightened a cord around Boëthius's forehead "so tightly that his eyes cracked in their sockets, and finally, while under torture, he was beaten to death with a cudgel."

After Boëthius, Mastership of the Offices went to another kinsman, **Cassiodorus**, whose writings provide some of the earliest extant records of Boëthius's life. Cassiodorus notes that Boëthius was skilled in both Latin and Greek, that his finest work was in logic, and that in the mathematical disciplines "he either equaled or surpassed the ancient authors."

One of Cassiodorus's tasks was to draft letters for Theodoric, and through some of these we see the esteem in which Boëthius had previously been held, and for which he had been elevated to such high rank. Especially respected was Boëthius's part in making Greek learning accessible to the Latin world. Theodoric noted Boëthius's practical side: the application of theory to produce toys, urban fortifications, what seems to be a fire-driven organ, and an orrery that demonstrated how lunar phases are produced. Theodoric acknowledged the usefulness of Boëthius's mathematics in coinage reform and, to demonstrate the royal endorsement of higher learning, Theodoric asked Boëthius to apply his astronomical skills to building a grand sundial (at public expense), augmented by a water clock for times when the Sun did not shine.

Boëthius planned to translate as much of **Aristotle**'s and **Plato**'s works as possible, to show that the two philosophers fundamentally agreed with each other, and to write commentaries on all of their works. This ambition went unfulfilled, at least partly because Greek texts were by this time scarcely available in the Latin West. Still, Boëthius did manage to translate nearly all of Aristotle's logical works, and he is credited with four theological works of his own, plus introductions to the four recognized mathematical disciplines: arithmetic, music, astronomy, and geometry. His introductions to arithmetic and music are extant: *On Arithmetic* is an expanded translation of the arithmetic by Nicomachus of Gerasa, much clarified and somewhat restructured; *On Music* is drawn from both Nicomachus and **Ptolemy**, set amidst the Pythagorean music of the spheres. Boëthius's theoretical tendencies are particularly evident in the musical treatise, so much so that Guido d'Arezzo, an 11th-century musical theorist, complained that it was "useful to only philosophers." But Boëthius's music is not only mathematics: It also covers music therapy, detailing the psychological effects of the Greek modes, and a physical theory of sound, attributing musical pitch to the frequency at which a string vibrates and strikes the surrounding air.

As for the texts on geometry and astronomy, we do not know whether Boëthius really wrote them. Their existence is testified in the 10th century by the mathematician **Gerbert d'Aurillac**, who reports having seen them at Bobbio. The astronomy, he says, filled eight books; the finely illustrated geometry two. But neither work has survived.

Boëthius's passion for mathematics is lengthily explained in the *Consolation of Philosophy* – written during the year or so awaiting execution – where Lady Philosophy, visiting Boëthius in his prison cell, persuades him that such learning leads to God and happiness. The *Consolation* is richly spiced with numerous astronomical snippets describing a Neoplatonist cosmos (geocentric celestial spheres governed by God who created them after ideal forms and maintains them in harmony), but these are generally allegorical and without much detail. Boëthius's second commentary on Aristotle's *On Interpretation* shows that he gave much reign to stellar influences on animals and humans, greatly constricting the scope for free will. He wrote in several places that studying philosophy naturally led him to work on understanding the heavenly motions. But little further evidence about Boëthius's astronomy is available: the orrery, water clock, and sundial mentioned by Theodoric.

Some centuries after his death, Boëthius's remains were transferred to Pavia, where they now lie in the Church of San Pietro in Ciel d'Oro, under an epitaph composed by Gerbert. In 1883 he was beatified, and his *cultus* officially confirmed.

Boëthius translated and wrote commentaries on all but one of Aristotle's logical treatises (*Topica*, *De interpretatione*, *Categoriae*, *Analytica priora*, *Analytica posteriora*, and *De sophistici elenchis*) and Porphyry's *Isagoge*. This group of translations served as a standard logical textbook through the Middle Ages.

Alistair Kwan

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Boguslawsky, Palon [Palm] Heinrich Ludwig von

Born **1789**
Died **1851**

Former military officer Palm Boguslawsky was director of the Breslau Observatory and an authority on the planet Uranus. Oddly, he does not appear in **Arthur Alexander**'s *The Planet Uranus* (New York: American Elsevier, 1965). Boguslawsky's successor at Breslau was **Johann Galle**.

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Bohlin, Karl Petrus Teodor

Born **Stockholm, Sweden, 30 October 1860**
Died **Ytterenhorna, Sweden, 25 May 1939**

Karl Bohlin was a theoretical astronomer, known primarily for work on the orbits of asteroids and other three-body problems.

Bohlin obtained a doctor's degree from Uppsala University in 1886. From 1886 to 1891, he taught at the Uppsala University and the Technical University in Stockholm, and was assistant director of the Stockholm Observatory. From 1891 to 1893, he was employed at the Rechen-Institut at the Berlin Observatory and in 1893/1894 at the Pulkovo Observatory to work on the orbit of comet 2P/Encke (named for **Johann Encke**). Bohlin was appointed director of the Stockholm Observatory in 1897 and served until his retirement in 1927. He helped found the Swedish Astronomical Society in 1919 and was its first chairman until 1926.

Bohlin primarily was a theoretician in celestial mechanics. He is known for his development of group perturbations of asteroids and work on the three-body problem. He measured and analyzed positions of planets, their satellites, and comets. He was probably the first to call attention to the asymmetric distribution of globular clusters and, assuming that they are centered on the galactic center, in 1909 he computed its longitude in excellent agreement with the current value. He also studied variable stars with a new reflector that he obtained for the Stockholm Observatory in time for the solar eclipse of 1914.

Helmut A. Abt

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Bohr, Niels Henrik David

Born **Copenhagen, Denmark, 7 October 1885**
Died **Copenhagen, Denmark, 18 November 1962**

Danish theoretical physicist Niels Bohr provided the first quantum mechanical description of atomic structure that was able to account reasonably well for the observed wavelengths of features emitted and absorbed by atoms in the laboratory and in stars. He received the 1922 Nobel Prize in Physics for this work.

Bohr was born to Christian and Ellen Adler Bohr. He had an older sister, Jenny, and younger brother, Harald, a successful mathematician and Niels's closest friend throughout his life. Christian Bohr was a university professor and physiologist. Just after Niels's birth, Christian was appointed a professor of physiology at the University of Copenhagen, replacing Peter Panum, and the Bohrs took up residence in Panum's professorial house. In 1891, Niels entered the Grammelholms School where his brother was also educated. Niels remained at Grammelholms until his graduation in 1903. He was a good student, though never at the very top in his class. It may be surprising to note that he excelled most at sport, being particularly adept at soccer, though it was his brother Harald who won a silver medal in soccer for Denmark in the 1908 Olympic Games in London. In the final 2 years at Grammelholms Bohr specialized in mathematics and physics where he began to show a particular aptitude, reportedly finding errors in the textbooks.

In 1903, Bohr enrolled at the University of Copenhagen studying physics as his major subject and mathematics, chemistry, and astronomy as his minor subjects. In 1906, he published the only paper describing experiments he carried out himself (in his father's physiology laboratory as there was no physics laboratory at the university). The paper won the Gold Medal of the Royal Danish Academy of Sciences and Letters. It was an analysis of the vibrations of water jets as a means of determining surface tension and built on the work of Lord Rayleigh. It also provided him with a basis for his later work on the liquid-drop model of the nucleus. Bohr received his master's in 1909 and his doctorate in 1911. Both degrees focused on the electron theory of metals and were purely classical in their approach. It was the limitations of the classical laws in describing the phenomenon that made him realize that there must be some radically different way of describing atomic processes. Bohr's doctoral dissertation was dedicated to the memory of his father who had died just months earlier.

In 1910, Bohr met Margrethe Nørlund. The two were married in August of 1912 and had a very close relationship. They had six sons, two of whom died in childhood. His son Aage (born: 1922) received the 1975 Nobel Prize in Physics for work on the structure of the nuclei of atoms, which had some conceptual similarities to his father's work on the behavior of electrons around those nuclei. In 1911, Niels Bohr made his first visit to Britain and the Cavendish Laboratory, then headed by the esteemed J. J. Thomson, discoverer of the electron. Bohr had hoped to interest Thomson in his work but was unsuccessful. However, he did meet and impress **Ernest Rutherford** with whom he developed a 25-year friendship. It was Rutherford who brought Bohr to the University of Manchester (then called Victoria University) and who showed that most of the mass of an atom resides in the nucleus. This was to be a major point in Bohr's development of his atomic model. He remained in Manchester for the year, returning to Copenhagen in July 1912 with his atomic model partly developed. He finally completed work on his atomic model in 1913.

The key issues of the Bohr model were, first, that an electron could exist only in certain orbits around the nucleus, each with a definite energy, and would emit or absorb radiation (light) only in transitions between orbits; and, second, that there would also be an atomic analog to the ellipticity of planet orbits and that electron orbits with different deviations from circles would have slightly different energies, making atomic spectra more complex than with just the basic circular orbits. These ideas were largely superseded in the period after 1925 when quantum mechanics came to be expressed in the more complex mathematics of differential equations and matrices.

Also in 1913, Bohr was appointed docent at the University of Copenhagen. The post did not afford him the freedom to explore mathematical physics as deeply as he wished, and Bohr wrote to the university petitioning them to create a professorship in theoretical physics. The university dragged its heels, and in 1914 Bohr accepted an offer to return to Manchester. Due to World War I, his stay in Manchester lasted longer than he anticipated but, finally, in 1916 the University of Copenhagen created the Chair of Theoretical Physics, and Bohr returned to Denmark to take up the post. It was the first time at the university that theoretical physics was recognized as a worthwhile discipline in its own right. It was then that he made yet another lifelong friend in Hendrik Kramers, who had come to Copenhagen in 1918 to escape the ravages of war and to study under Bohr. The two would collaborate on numerous scientific and social issues over the next 40 years. In 1917, Bohr was elected to the Royal Danish Academy of Sciences and Letters and soon began, eventually with Kramers's aid, to plan the development of the Institute for Theoretical Physics (later the Niels Bohr Institute).

Modern quantum mechanics was born around 1925, and in 1927 Bohr published his first work on complementarity. This led to a long, public debate between Bohr and **Albert Einstein** over the philosophical foundations of quantum theory. In 1926, Bohr was elected a fellow of the Royal Society, and he received the Society's Copley Medal in 1938. In 1932, the Bohrs moved from their house at the institute to a mansion at Carlsberg donated to the Royal Danish Academy of Sciences and Letters by the Carlsberg Foundation, which had supplied Bohr with research funding in prior years. The academy, of which he was president for many years, offered the home to Bohr for the remainder of his life.

In 1937, Bohr and his family toured a number of countries where he gave lectures and, while in Britain, spoke at Rutherford's funeral. On returning to Denmark, the looming war brought great changes in Bohr's life. Though raised a Christian, his mother was Jewish and the Nazi occupation of Denmark in 1940 made his life difficult. It was not made easier by a visit in autumn 1941 from

Werner Heisenberg, who had been a close colleague and friend before the German occupation of Denmark, which put them firmly on opposite sides of World War II. Precisely what happened during that visit has been explored at great length in both history books and a somewhat fictionalized play called *Copenhagen*. In 1943, encouraged by the British government, Bohr and his family escaped to Sweden in a fishing boat. From Sweden he flew to Britain where he began work developing a nuclear fission bomb. After a few months, the entire British team was sent to Los Alamos in the United States to collaborate on the Manhattan Project where Bohr was officially referred to as "Dr. Baker." Almost immediately, however, he became concerned with the social and political implications of the bomb, writing a letter in 1944 to President Roosevelt and Prime Minister Churchill urging them to promote international cooperation. Later, in 1957, Bohr received the first United States Atoms for Peace Award and continued throughout the remainder of his life, often in conjunction with his old friend Kramers who was chair of the United Nations committee on nuclear policy, to argue for nuclear arms control.

In the autumn of 1945, Bohr returned to Copenhagen where he regained his post and his home in Carlsberg. Much of his time over the next decade was spent planning the Danish Atomic Energy Commission's research establishment at Risø. At the beginning of the 1960s, he and members of his institute began planning for a meeting in 1963 to celebrate the 50th anniversary of the publication of his original papers on atomic theory. Unfortunately, Bohr died a year before of a heart attack, leaving a legacy as one of history's greatest physicists. On an astronomical note, there is a crater on the Moon named for him.

Ian T. Durham

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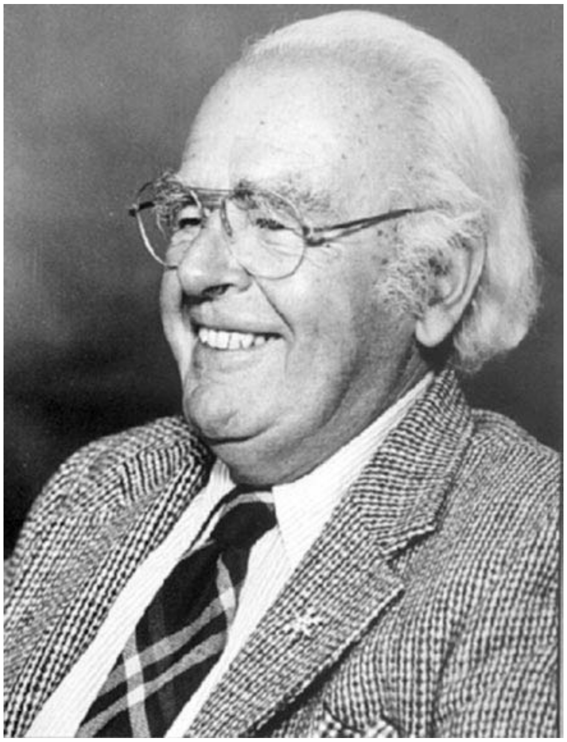
Bok, Bart Jan

Born **Hoorn, the Netherlands, 28 April 1906**
Died **Tucson, Arizona, USA, 5 August 1983**



Bart Bok was the son of Sergeant Major Jan Bok (Royal Dutch Army) and Gesina Annetta (*née* van der Lee) Bok. Bart Bok's name is associated with the Bok globules, small, dark, gas clouds, many of which are forming-or about to form-new stars. He was also one of Harvard's early champions of star formation as an important, on-going process, at a time when **Jesse Greenstein** and others were not so sure. He attended primary school in Hoorn and secondary school in The Hague. Bok entered Leiden University in 1924; two of his classmates were **Gerard Kuiper** and Pieter Theodorus Oosterhoff. Upon graduation in 1927, Bok was accepted by Groningen University, where he pursued a doctorate in astronomy under **Piet van Rhijn**. He studied the η Carinae region for his dissertation; his Ph.D. was awarded in 1933. In 1929, Bok married astronomer Priscilla Fairfield; the couple raised two children. He became an American citizen in 1938.

The majority of Bok's career was spent at Harvard University; he received the Robert Wheeler Wilson Fellowship (1929–1933) while still a graduate student. In succession, Bok was appointed assistant professor (1933–1939), associate professor (1939–1947), and the Robert Wheeler Wilson Professor of Astronomy (1947–1957). For six of those years, Bok was also associate director of the Harvard College Observatory (1946–1952).

An astronomical leader on two continents from 1957 to 1966 Bok was professor and head of the department of astronomy at the Australian National University and director of its Mount

Stromlo Observatory. He thereupon returned to the United States as professor and head of the astronomy department at the University of Arizona and director of its Steward Observatory (1966–1970).

During his Harvard years, Bok established a network of colleagues who were engaged with him on a program to determine the interstellar extinction rate at low galactic latitudes. Three of these "star counters" were Sidney W. McCuskey (Case Institute of Technology); Robert H. Baker (University of Illinois); and Edwin C. Carpenter (University of Arizona). Bok made annual "inspection trips" to cheer on his troops and to discuss their preliminary results. It was this activity that first led Bok and his wife to consider the University of Arizona and its Steward Observatory as the final "resting place" in their professional careers.

In the early 1940s, Bok led the way for an astrophysical observatory to be built in Mexico. A 26/31-in. Schmidt telescope was established at the Observatorio Astrofísico de Tonantzintla with assistance from astronomers at the Mexican National University. The facility was opened in 1942 and first directed by **Luis Erro**.

In 1950, Bok repeated the exercise by establishing a 24/32 in. Schmidt telescope, the so-called "Armagh–Dunsink–Harvard Telescope," at Harvard's Boyden Station in South Africa. There, Bok was able to collect a large number of plates for his enduring study of interstellar extinction in the galactic plane.

In 1944, Hendrik C. van de Hulst, a research student at Leiden Observatory in the Netherlands, predicted the existence of a spectral line of cold, neutral, hydrogen due to an atomic hyperfine transition at the 21-cm wavelength. For his 1950 doctoral dissertation, Harvard physics graduate student Harold I. Ewen, working with Edward Durall, observationally confirmed Van de Hulst's prediction. Typically, Bok was the first American astronomer to seize upon this opportunity. In 1952, he rustled up the funds necessary to build a 24-ft steerable antenna at Harvard's Oak Ridge Station. With receivers built especially for the 21-cm/1420 MHz-radiation, he began a series of studies on the occurrence of neutral hydrogen in the plane of our Galaxy. A number of young radio astronomers emerged with new doctorates from this work, among them were Nannie Lou Dieter, Frank D. Drake, and David L. Heeschen. Not all senior American astronomers, however, were of the opinion that radio astronomy was worth the effort. Bok was often advised to get on with doing useful, *i. e.*, *optical*, research. But he persisted.

In Australia, Bok encouraged collaborative efforts between the radio astronomers at the Commonwealth Scientific and Industrial Research Organization [CSIRO] and the optical astronomers at Mount Stromlo. Always a champion of research on the Magellanic Clouds, Bok collaborated with the Swedish government to have yet another Schmidt telescope installed at Mount Stromlo. There, Uppsala University detailed one of their staff astronomers, Bengt E. Westerlund, as a resident observer.

Bok also led the charge to find a site for a modern, large (4-m class) reflector, to replace the aging 74-in. telescope at Mount Stromlo. This resulted in the establishment of a facility at Siding Springs, starting with a 1-m Ritchey–Crétien reflector and, after Bok's departure for Arizona, the 3.5-m Anglo–Australian Telescope.

After accepting the post at the University of Arizona, Bok was able to obtain a grant from the United States National Science Foundation to change the complexion of the university's small Steward Observatory. The grant amounted to $2.6 million, and Bok's solution was to build and equip the largest telescope he could get for that amount of money. By these means, the Observatory's 90-in. reflecting telescope was acquired.

When Bok arrived in 1966, the scientific staff at the observatory consisted of five astronomers, five graduate students, one secretary, one machinist, and one staff photographer. After Bok retired in June 1970, the count was 15 astronomers, more than a dozen graduate students, 12 undergraduate students, four secretaries, and 14 technical support personnel (including the same staff photographer). On 28 April 1996, which would have been Bok's 90th birthday, the 90-in. reflector was renamed the Bart J. Bok Telescope.

Bok belonged to many professional organizations and received numerous awards. He was a member of the American Association for the Advancement of Science, vice president (1970–1971) and president (1971–1972) of the American Astronomical Society, board member of the Astronomical Society of the Pacific, member of the National Academy of Sciences and the Royal Astronomical Society, and vice president of the International Astronomical Union (1970–1974). He received the Bruce Gold Medal of the Astronomical Society of the Pacific (1977), the Jansky Prize of the National Radio Astronomy Observatory (1972), the Henry Norris Russell Lectureship of the American Astronomical Society (1982), and the Klumpke–Roberts Award of the Astronomical Society of the Pacific (1982).

Bok's own enthusiasm for his subject was infectious and always invigorating. Moreover, this enthusiasm carried over into "Town and Gown" situations. He was always willing to talk to the public about astronomy. His lectures, given during the Steward Observatory public evening series, were always delivered to standing-room-only audiences.

A bout with polio in 1939 left Bart with a withered right arm and unfit for military service during World War II. However, he and Harvard colleague Frances Woodworth Wright wrote a book together, *Basic Marine Navigation*, intended for use by the United States armed forces, especially for the Navy's V-12 program. Wright eventually turned that enterprise into a book of her own, with Bok's blessing, entitled *Celestial Navigation*.

The 1947 paper announcing the first set of Bok globules was co-authored by Edith F. Reilly, who also had a physical handicap and was only briefly part of the astronomical community. Bok's life was filled with writing projects, not only for scientific research publications, but also for public information and consumption.

Raymond E. White

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Bond, George Phillips

Born **Dorchester, Massachusetts, USA, 20 May 1825**
Died **Cambridge, Massachusetts, USA, 17 February 1865**

As the second director of the Harvard College Observatory, George Bond's tenure, from 1859 to 1865, was tragically short. However, in his career Bond managed to make significant contributions to astronomical science in his comet and nebula observations as well as through his early experimental work in astronomical photography. As the son of the first Harvard director, **William Bond**, he served for years as his father's assistant, and was appointed director of the observatory shortly after his father's death. While George Bond's career must be seen in the context of his father's, he was clearly more highly trained and mathematically proficient. He directed the observatory at a time when its role and the climate of science in America were both changing.

George Bond was born in Dorchester and moved to Cambridge when his father assumed directorship of the Harvard Observatory in 1839. Unlike his father, who was financially unable to complete his public education, George received a fine education. He attended the then famous Hopkins Classical preparatory school in Cambridge and graduated from Harvard University in 1845. By all accounts he was a serious and dedicated student who excelled in mathematics. He also had a strong interest in natural history and is said to have considered a career in this field. However, the death of his older brother William compelled him to take up the role of his father's assistant.

George's astronomical career began while he was still a student. As early as 1842 he is reported making observations in the small observatory used before the 15-in. "great refractor" was installed. Not long after graduation George was hired as the observatory's assistant observer. Despite being offered other positions, he remained in this post until his father died in 1859.

Much of George Bond's observing career centered on the study of comets. Between 1845 and 1851, at a time when finding comets was a major mark of an observer's skill, he made independent discoveries of 10 comets, of which one actually bears his name (C/1850 Q1). His monograph on comet C/1855 L1 (Donati), "Account of the Great Comet of 1858," was probably his most important scientific contribution. It was widely praised and resulted in his being awarded the Royal Astronomical Society Gold Medal in 1865. Bond was the first American to receive this award.

Because George and his father worked closely together over a period of many years, and because of the son's deference to his father's reputation, it is difficult to parse the achievements of the two men. They collaborated on several visual studies, including sunspots (from 1847 to 1849), Saturn (1847–1856), and Jupiter (1847–1849). The two also collaborated on studies of the Andromeda and Orion nebulas and the Hercules cluster. In 1848, they codiscovered Saturn's eighth moon Hyperion. George is generally credited with being the codiscoverer, with **William Rutter Dawes**, of the faint inner or crépe ring of Saturn.

The two Bonds also collaborated (along with Boston photographer John Adams Whipple) in early attempts to photograph the heavens. From 1849 to 1851 they experimented with daguerreotypes. In 1850, the three succeeded in recording the first image of a star (Vega or α Lyrae) on a daguerreotype. In 1851, using short exposures and at a separate photographic focus, they succeeded in taking a series of beautifully clear images of the Moon. George Bond displayed these daguerreotypes to great effect when he visited Europe in 1851. Beginning in 1857 the younger Bond, working with Whipple and his partner James Wallace Black, took a series of between 200 and 300 collodion photographs through the large telescope. The more sensitive film and longer exposures, achieved with the telescope's improved clock-drive, allowed them to photograph stars as faint as 6th magnitude. As part of this work, Bond made preliminary stellar and photometric measurements. The difficulties of working with collodion films made such work impractical at the time, but Bond clearly showed the possibilities of the new technology.

As his father's assistant, George Bond participated fully in the observatory's longitude work. He directed the United States Coast Survey Chronometric Expeditions (1849–1855) and made the data reductions that led to the most accurate determinations of American longitude to date. He also was a key participant in the work to develop a telegraphic method of determining longitude (what came to be called the American method). In 1851, George was chosen to take the longitude instruments developed by the Bonds to London, where they were demonstrated and exhibited at the Crystal Palace Exhibition. The instruments were awarded a Council Medal, the exhibition's highest award.

By the 1850s, George Bond had developed a reputation as a first-rate astronomer, and the Harvard Observatory had become the *de facto* national observatory for many. In 1856, he was offered the prestigious position of chief astronomer of the Northwest Boundary Survey, charged with establishing the American–Canadian border. Although he declined the offer, it indicates the high regard in which he was held.

Unlike his father, who pursued his entire career with little controversy, George Bond was unable to avoid professional disputes. The most serious was with fellow Harvard astronomer **Benjamin Peirce**, who first quarreled with Bond over their articles on the structure of Saturn's rings. Peirce's hostility became resentful and openly critical when he was denied the position of observatory director after William Bond's death. Within a month of being named director George wrote to Peirce, offering a reconciliation and access to the observatory. Peirce never responded. Bond believed that his later failure to be elected to the National Academy of Sciences was at least partly due to Peirce's influence.

In 1857 **Otto Wilhelm Struve**, sharply criticized the Observatory's work on the Orion nebula. Rising to what he perceived as a criticism of the observatory as well as his father, George became determined to produce a definitive study of the nebula and spent the winters of 1857, 1858, and 1859 making detailed observations. He had to postpone the project to finish his work on Donati's comet, but in the last days of his life he worked diligently, but unsuccessfully, to finish it. Bond's work on the Orion nebula was completed and published by **Truman Safford** before the latter accepted the directorship of the Dearborn Observatory when it first opened.

After several years of delicate health, William Bond died. Tragically, the death of George's father and his appointment as observatory director also coincided with the death of George's wife, Harvard librarian Harriet (*née* Harris) Bond, who died in December 1858. At about the same time, Bond experienced the first symptoms indicating that he had contracted tuberculosis. Despite heroic efforts to keep working, George Bond's remaining years were characterized by generally declining health and energy.

Bond took over the observatory at a time when its role was changing, a factor making his directorship even more complicated in the face of the adverse influences of his personal and health problems. Much of the longitude and other practical work that had for many years provided the main grist of the observatory workload was no longer a priority or was being provided by other sources. Federal contracts and income ended by 1862, and by then the Civil War was draining resources of all kinds. In 1863, Bond wrote to a colleague that all but one of his assistants had either enlisted or been drafted into the Union Army.

Despite these problems, Bond gamely tried to improve the observatory. Determined to acquire a larger telescope, he first attempted to buy the exquisite 18½-in. refracting telescope lens produced by Alvan Clark & Sons for the University of Mississippi. When the Civil War broke out and the university lost its ability to pay for the lens, Bond negotiated to purchase the lens, but the Clarks eventually sold it to the Chicago Astronomical Society for use at the Dearborn Observatory. Bond made a second trip to Europe in 1863 in search of a new larger instrument, but nothing came of it.

George Phillips Bond made his last astronomical observation on 24 August 1864. His strength continued to fade until he finally died.

Steven Turner

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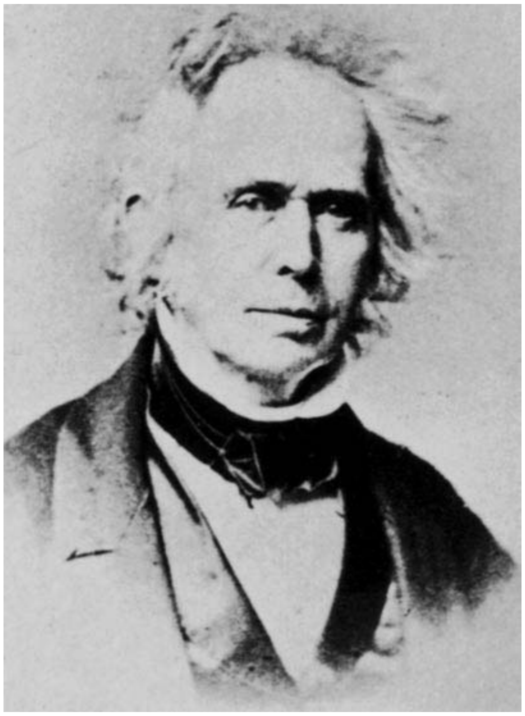
Bond, William Cranch

Born **Falmouth (Portland), Maine, USA, 9 September 1789**
Died **Cambridge, Massachusetts, USA, 29 January 1859**



As the first director of the Harvard College Observatory, from 1839 to 1859, William Bond was one of the major figures in *antebellum* American astronomy. His work as an astronomer was more closely linked to institution building, his business, and to the needs of commerce than it was to the basic observational or theoretical astronomical work of his times. Biographies of his life have generally focused on his rise from humble beginnings, his remarkable mechanical abilities, and his role in establishing the Harvard College Observatory. Recent research has centered more on his work as a provider of precise time and position measurements to the developing nation and his role in the scientific network that developed around Cambridge during his lifetime.

Financial hardship soon caused his family to move to Boston, Massachusetts, where his father, William, started a watch and jewelry business. As a boy Bond showed great mechanical aptitude, building a weight-driven chronometer at age ten and a fine wooden quadrant at age 16. In 1812, he completed what was reputed to be the first sea-going chronometer made in America. Under his direction the Bond firm expanded into the important marine chronometer trade and later provided precision astronomical regulators to American customers. The nature of both enterprises meant that the firm engaged in extensive trade with British suppliers and customers.

As a young man William showed an intense interest in astronomy, which he attributed to seeing the solar eclipse of 1806. Despite being largely self-taught and lacking proper instruments, he was the first American to observe and track the comet of 1811(C/1811 F1). This brought him to the attention of Harvard professor John Farrar and later the famed **Nathaniel Bowditch**, both of whom encouraged and assisted Bond. In 1815, upon learning that Bond was planning to travel to England, Farrar was instrumental in having the college ask Bond to visit Greenwich Observatory and the London instrument makers. For the college this was a preliminary step in the eventual construction of an observatory. For Bond, who met not only the Royal Astronomer **John Pond** and **William Herschel**, but also a host of other luminaries of British astronomy, it must have been a powerful formative experience.

Indeed, Bond's passion for astronomy was so great that he converted the parlor of his home in Dorchester into a transit room, installing a massive granite pier in the center of the room and a meridian opening in the ceiling. With this and a growing collection of other instruments he used his private observatory to pursue a regular observing program, determining (among other things) his precise longitude. He also used his observatory to support his business. Beginning in 1834, he had a series of contracts with the United States Navy to rate and maintain ships' chronometers, and in 1838 he received an appointment from the federal government to assist the Wilkes expedition, providing meteorological, magnetic, and astronomical observations.

Bond brought this practical approach to astronomy with him when in 1839 he accepted Harvard College president Josiah Quincy's invitation to become the school's astronomer. Harvard's choice of Bond was a logical one; he already was known to be a first-rate observer, and his ongoing work on the Wilkes expedition was sure to bring prestige to the college. As a bonus, Bond brought all his instruments with him, and these were much superior to the few telescopes then owned by the college. Bond received no salary until 1846 but was provided living quarters and space for his instruments.

The great comet of 1843 (C/1843 D1) drew the attention of many Americans to the heavens. In Cambridge, reports that Bond's instruments were inadequate to chart the orbit of the comet soon led to a spontaneous public campaign that raised $20,000 to purchase a proper telescope. On his own, businessman David Sears donated another $5,000 for a stone pier. By 1847, the great 15-in. Merz and Mahler refractor – the great equatorial – was in place and ready to use. In less than 7 years Bond had taken Harvard College from astronomical obscurity to possession of a telescope equal in size to any in the world.

The uses that Bond made of this new instrument and the other resources at his disposal reflect his background as a "mechanic" and his belief that science should be "useful." While it is often difficult to separate his work from that of his son and collaborator, **George Bond**, certain broad statements can be made: First, that although he was a diligent and accomplished observer, his main contributions to astronomy were his technical innovations. Second, that while other astronomers, like Harvard's professor of mathematics and astronomy **Benjamin Peirce**, may have advocated a program of theoretical research, William Bond chose to devote large amounts of the observatory's resources to purely practical interests. Nonetheless, under his direction the Harvard College Observatory succeeded on many levels.

From 1847 to 1856 William Bond and his son made an extended study of Saturn. In 1848, they discovered Saturn's moon Hyperion and later made detailed observations of the faint ring structures. The Bonds also made visual studies of other planets and, particularly, the nebulae in Andromeda and Orion. Between 1847 and 1849 they used a smaller refractor to make a series of nearly 250 sunspot drawings. In 1849, William was elected a Foreign Associate of the Royal Astronomical Society.

William Bond also made significant improvements to the large telescope itself: first with an ingenious observer's chair and then in 1857 with a much improved clock drive, designed by the Bonds and manufactured by the Cambridge telescope maker **Alvan Clark**.

With much assistance from his son George and Boston photographer John Adams Whipple, William also pioneered the application of photography to astronomy. In July 1850 they took the first successful picture of a star, a daguerreotype of Vega (α Lyrae). After the new drive was installed, they experimented extensively with the newly developed wet-plate collodion process, eventually taking between 200 and 300 photographs of the heavens.

Concurrent with his work as an observer, William Bond also continued to accept assignments from federal agencies. In the mid-1840s, following the lead of other national observatories, he began to ship chronometers between Cambridge and Liverpool with the goal of precisely determining the longitude of the observatory. In 1849, **Alexander Bache**, head of the United States Coast Survey, gave formal sponsorship for this project, and the Bonds transported groups of chronometers across the Atlantic in a series of trials that finally ended in 1855. Eventually Cambridge's position was so precisely determined that it became the reference point for the United States Topographical Engineers and the *de facto* American meridian.

Also in the 1840s, Bond and his sons George and Richard became key players in the American efforts to determine longitude telegraphically. They were instrumental in the development of a workable break-circuit device to automatically transmit time signals over the telegraph and also developed the drum chronograph, which was later widely used in American observatories. Despite priority disputes, the Bonds exhibited the "American Method" of determining longitude at the 1851 London Crystal Palace Exhibition. They received a Council Medal, the exhibition's highest award.

Under Bond, work at the observatory overlapped with the activities of his business. In 1851, he installed the world's first telegraphic time service in the observatory, providing astronomically derived signals to keep the railroads safely on time – and indirectly providing standardized time to large parts of the northeastern United States. The signals were supplied through the Bond & Sons firm, which also supplied timekeepers to the railroads. Although clearly serving a commercial purpose, under Bond the observatory provided this service without compensation. Bond saw it as part of the observatory's mission to be "useful." Later in the century, selling time became a significant source of revenue for many American observatories.

Bond's last few years were characterized by delicate health, and many of his duties were assumed by his son George. Of his other assistants, **Truman Safford**, **Asaph Hall**, and William Rogers were later ranked among the country's most talented astronomers. His son George, a talented astronomer in his own right, succeeded him as director of the Harvard College Observatory.

Steven Turner

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Borda, Jean-Charles de

Born **Dax, (Landes), France, 4 May 1733**
Died **Paris, France, 19 February 1799**

Jean-Charles de Borda was a positional astronomer, instrument designer, and one of the founders of the metric system. Borda was born in a noble family, son of Jean-Antoine de Borda and Jeanne-Marie Thérèse de Lacroix. He began his education at the Jesuit school La Flèche, and later entered the light cavalry and then the Academy of Engineers of Mézières. His scientific curiosity made him eligible for the Paris Academy of Sciences in 1756. Borda's first publications in the annals of the academy deal with a subject not directly related to astronomy: the resistance of fluids. In 1769, due to Aymar Joseph de Roquefeuil's insistence, the Marine Academy was created, and Borda was elected a member and professor of mathematics. There, he developed a great deal of his astronomical knowledge.

In 1771, Borda embarked on the frigate *La Flore*, destined for America. He was accompanied by the astronomer **Alexandre Pingré**, with the goal to study the behavior of chronometers and to determine their utility when using the lunar-distances method to determine longitude at sea. The simplified method, which Borda tested on this trip and was published in two volumes with tables in 1778, became common practice in the French navy. Simplified versions of the method were also published in the *Connaissance des temps* in the years 1779, 1780, and 1787.

Borda specialized in positional astronomy to be used in navigation and astronomical instrumentation, and in this field he accomplished his best work. Other trips to America and Africa sealed his fame as a sailor and as an educated scientist. He was named captain, and was captured during combat by the British in 1782 and in 1784. With his health too weak for life at sea, Borda was named superintendent of construction of the school of naval engineers. In 1795, at its creation, he was also selected a member of the Bureau of Longitudes.

From 1778 Borda perfected an instrument adumbrated by **Tobias Mayer** in 1752, which he named the "repeating circle" or "astronomical circle." Borda's circle competed with the traditional quadrant used for astronomical measurements both at sea and on land, and its superiority was manifested in the operation of the geodesic union of the observatories in Greenwich and Paris, which took place in 1787. Under his direction, the artist E. Lenoir made a great number of instruments of various dimensions. In 1801, the Spanish astronomer and mariner José de Mendoza introduced new improvements that led to the instrument's definitive shape for use in navigation and in terrestrial operations. Borda also calculated, in subsequent years, numerous trigonometric sexagesimal and centesimal tables for better use of the instrument.

As an expert observer and a careful experimenter, Borda's name was associated from the very beginning with the activity that would be the most important of his later years: the work on the basis of a new system of weights and measures promoted by revolutionary France. It was his initiative, on record in the *Procès verbaux de l'Académie des sciences*, to create a commission that drew up the definitive project. Indeed, on 16 February 1791, the academy selected him along with **Pierre de Laplace**, J. A. Condorcet, **Joseph Lagrange**, and Gaspard Monge to propose a new model of measurements founded on the length of a terrestrial meridian. The report on 19 March 1791 constituted without a doubt the origin of the decimal metric system, which became the international system of weights and measures. In his work to define the metric system, Borda displayed an unwearied activity up until his death. He was in charge along with C. A. de Coulomb of measuring the length of the pendulum that marked seconds at the 45° parallel. Borda verified the rules used to measure the geodesic bases and to determine the model kilogram. He supervised the construction of repeating circles, which **Jean Delambre** and **Pierre Méchain** used in their measurements.

On 5 July 1795, Borda presented his *Rapport sur la vérification du mètre qui doit server d'étalon pour la fabrication des unités républicaines*, which introduced the provisional meter, and was part of all the commissions that determined the definitive meter. In the middle of these efforts to officially approve this new measurement, Borda died.

Antonio Ten
Translated by: *Claudia Netz*

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Borelli, Giovanni Francesco Antonio Alfonso

Born **Naples, (Italy), January 1608**
Died **Rome, (Italy), 31 December 1679**

Giovanni Borelli was an early Italian Copernican, experimenter, and observer. Christened on 28 January 1608 in Naples, he was born to Miguel Alfonso, an itinerant soldier in the occupying Spanish army, and Laura Porrello (also called Borrelli in some records), a native of Naples. Giovanni and his brother Filippo later took the name Borelli, although why is unknown.

The brothers met the controversial philosopher Tommaso Campanella around 1626 and both became his students. Filippo, who fled to Paris in 1634 with Campanella, edited the latter's works and appears to have returned to Italy and entered the Dominican order, taking the name Tommaso. After 1628, Giovanni Borelli went instead to Rome, where he studied under **Benedetto Castelli**, who held Borelli in high esteem.

In 1635, Castelli recommended Borelli to fill the vacant mathematics chair in Messina and later, in 1640, recommended him, unsuccessfully, to **Galileo Galilei** for a similar chair at Pisa, one he eventually gained in 1656.

Borelli began his career in Messina inauspiciously, it appears, being at first a very unsuccessful lecturer, but improved considerably in time and attracted wide student interest. He also became central to the intellectual life of the university despite his lack of published output. In 1642, the Senate of Messina enjoined Borelli to travel through Italy recruiting talented faculty for the university, a journey that brought him into contact with many of the leading lights of the Italian scientific community and broadly established his reputation and broadened his own education. He remained in Messina until 1656, publishing several works in mathematics and displaying a growing expertise in theoretical medicine but not evincing any special interest in either physics or astronomy. However, his Copernican interests were becoming known, because in 1650 he was passed over in a bid for the chair of mathematics in Bologna, which was given to **Giovanni Cassini**; his philosophical position may have been a factor. Eventually, in 1656, Borelli managed to succeed to the chair of mathematics at Pisa previously occupied by Galilei and Castelli, relocating to Tuscany and beginning the most intellectually productive period of his life.

The Medicis, who controlled the university and the city, were deeply affected by and sympathetic to the Galilean scientific program, especially the princes Leopold and Ferdinand who were the founders of the Accademia del Cimento. This was a group of dedicated empiricists that included Vincenzo Viviani, the last pupil of Galilei, Carlo Rinaldi, and the Danish philosopher Nicholas Steno. After his arrival in Pisa, Borelli became central to its activities, and was perhaps its most visible, and contentious, member; it lasted from 1657 through 1667. Although publishing anonymously, like the later Bourbaki collaboration whose members published only as a collective, it is clear that much of the work of the Accademia was Borelli's. The works of the Accademia, finally collected and published in 1667 as the *Saggi di naturali esperienze fatte nell'accademia del cimento*, not only ranged over a broad experimental territory, mainly pneumatics, thermal physics, and fluids, but also included astronomy.

For instance, following **Christiaan Huygens**' announcement of the discovery of a ring system around Saturn in 1660, Borelli conducted what may be the first experimental study of observer effects. He constructed a scale model of Saturn with an inclined ring that was observed at a distance with the unaided eye and lenses to simulate the planet's angular diameter and approximate illumination, showing that the model reproduced the explanation. At a distance of 23 m, the appearance to the unaided eye in daylight illumination was a sphere flanked by two stars; at 75 m with a small telescope it displayed the rings and shadow clearly as Huygens had described. This also explained the results obtained by Galilei and others with more imperfect telescopes.

Finally, uninformed observers of the Accademia were asked to sketch the appearance, foreshadowing an experiment conducted at the start of the 20th century by **Simon Newcomb** for the Martian canals.

Borelli displayed a lively interest in astronomy during his years in Tuscany. In an interesting prediction for the lunar eclipse of 16 June 1666, Borelli calculated that atmospheric refraction would permit the simultaneous observation of the Moon in eclipse, which occurred at sunset, and the rising Sun; an expedition organized by the Accademia to the island of Georgina in the Tyrrhenian Sea confirmed this and determined an atmospheric refraction of nearly 1°. A similar prediction for Venus, that on 21 and 22 April 1662 it would be both the morning and evening star, was not confirmed because of the weather and was not attempted again.

Borelli also engaged in observations of comets C/1664 W1 and C/1665 F1. He demonstrated that the motion followed a curved orbit akin to a parabola, and that the comet's lack of parallax placed it above the Moon. Both were clearly Copernican results and sufficiently sensitive that the work, *Del movimento della cometa apparsa nel mesi di dicembre 1665*, was published in Pisa under a pseudonym, Pier Maria Mutoli.

Borelli also established an observatory in San Miniato, near Florence, during the summer of 1665. The next year saw publication of his *Theoricae mediceorum planetarum ex causis physicis deductae*, his most important work in astronomy in which he sought to explain the elliptical orbital motion of the Jovian moons through a combination of centripetal tendencies because of the ponderous nature of the satellites' rotationally driven torques – much as **Johannes Kepler** had done for the planets driven by the solar rays and/or magnetic field – and centrifugal forces. In this work, he failed to appreciate the role of inertia requiring active tangential driving by the central body, but anticipated the importance of radial equilibrium between the gravitating tendency of the body and its centrifugal deviation.

In 1667, Borelli returned to Messina to renew his appointment as professor of mathematics, also taking an active role in scientific academies in Naples and Rome. He ultimately fled to Rome in 1672 with a prise on his head – as Campanella had so many years before – following a political dispute with the ruling Spanish government in Messina. Borelli received the patronage of Queen Christina of Sweden, whose connections with **René Descartes** are well known, and who supported publication of his final work on anatomy and musculature. Suffering serious financial difficulties in his last years, Borelli lodged with the order of Casa di San Pantaleo in Rome after 1677, teaching at their school, and died there.

Borelli also had an international reputation as an important telescope maker. In his later years, his advice was sought by **Jean Cassini**, then director of the Paris Observatory, and **Jean Picard**. **John Flamsteed** procured a 90-ft focal length lens from him for the newly founded Royal Observatory at Greenwich in 1675.

Steven N. Shore

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Boskovic, Rudjer [Roger] J.

Born **Ragusa (Dubrovnik, Croatia), 18 May 1711**
Died **Milan, (Italy), 13 February 1787**

The polymathic Jesuit Rudjer Boskovic contributed to practical and theoretical mathematics, optics, and astronomy. He was born to Nikola Boskovic, a merchant, and Paula Bettera. After his early education at the Jesuit school in Ragusa, Boskovic entered the Jesuits in 1725 and then studied at the Collegium Romanum. He advanced quickly in his studies. He was made professor of mathematics at the Collegium Romanum in 1740 before he was ordained and even before he finished his course of theology. In 1759, Boskovic left Rome for Paris, to the Academy of Sciences, of which he was a corresponding member. After staying there for half a year, he traveled first to London, where he met many scientific and philosophical noteworthies before continuing to tour Europe and returning to Italy in 1763. Boskovic became professor of mathematics in Pavia, where he focused on optics and also led efforts to build the Brera Observatory in Milan (though his plans were not fully carried out). In 1770, he moved to the Scuole Palatine in Milan, but trouble led to his resignation of his professorship in 1772. When Pope Clement XIV banned the Jesuit order the following year, Boskovic moved to Paris, where he again concentrated on optics and astronomy as captain of optics in the French navy. In 1782, he returned to Italy, eventually settling down in Milan, where he worked at the Brera Observatory until his death.

Boskovic argued against blind loyalty to Aristotelian physics and did not suffer fools gladly. This characteristic led to many disputes and contributed to many of his political difficulties. In his early days, Boskovic was not allowed to teach openly the Copernican system as a fact. Out of respect for the Roman Inquisition, Boskovic taught it as a mathematical hypothesis and mentioned the need to satisfy censors in order to acquire the imprimatur, but urged its acceptance nonetheless. His influence helped minimize the hostility of Catholic churchmen to the Copernican system, and he convinced Pope Benedict XIV to remove *De Revolutionibus* from the Index of Forbidden Books.

Boskovic demonstrated considerable practical and theoretical talent. He was commissioned to repair the fissures in Saint Peter's dome as well as in other cathedral domes, to direct the drainage of the Pontine marshes, and to survey the meridian of the Papal states. His practical inventions include the ring micrometer, which enabled him to determine the relative positions of two heavenly bodies. Boskovic was the first to apply probability to the theory of errors, as was later acknowledged by **Pierre de Laplace** and **Carl Gauss**. His ideas also led to methods developed by Laplace and Gauss to compute the orbits of comets and asteroids. In his analysis of the *vis viva* controversy, about which he concluded that it was a verbal rather than a philosophical problem, Boskovic also first expressed his atomic theory based on a universal force law describing both attractive and repulsive regions; he developed the details of this theory in his *Theoria Philosophiae Naturalis.*

Boskovic's interest in astronomy led him to a complete study of optics, optical instruments, and the theoretical foundations and instrumental practice of observational astronomy. He formulated a general photometric law of illumination, developed a law of light emission, and worked for the improvement of lenses and optical devices. His *Dioptrics* addresses many principles of telescopic observation, including achromatic lenses and the importance of eyepieces; it also offers an impressive example of Boskovic's accuracy in measuring the reflection and dispersion of light using his own invention, the vitrometer. Boskovic's astronomical efforts yielded many other results as well, including methods to determine the Sun's rotation, details of the transit of Mercury, and observations of the aurora. In 1753, he refuted **Leonhard Euler**'s analysis of the lunar atmosphere, arguing that it was, at best, far less dense than supposed. In 1766, Boskovic communicated to **Joseph de Lalande** a method of measuring the speed of starlight by use of a telescope filled with water to discover whether light travels with the same velocity in air and in water. In 1770, as the first director of the Brera Observatory, he made preparations to carry out this experiment, but could not do so before his removal.

Boskovic was a correspondent for the Royal Society of London and a frequent contributor to the Jesuit periodical *Mémoires des Trévoux.* He regularly encouraged international scientific cooperation. He helped convince the Royal Society to form an expedition to observe the 1761 transit of Venus, but was unable to participate in the observations himself. The Royal Society subsequently invited Boskovic to lead a trip to California to observe the 1769 transit of Venus, but this was canceled for political reasons.

Boskovic lived a long, fruitful life in which he explored diverse interests. Eastern European and Russian scientists have long shown a strong interest in his work; more recently, Western scientists have become better acquainted with his contributions, yielding a host of recent books and articles. His legacy has been preserved in the special Boskovic Archives in the Rare Books Library at the University of California in Berkeley. The nearly 200 items housed there include many of his 66 scientific treatises and over 2,000 letters of correspondence with other mathematicians, including Laplace, **Jean D'Alembert**, **Daniel Bernoulli**, Euler, and **Joseph Lagrange**. Various symposia have been held on the anniversaries of Boskovic's publications, birth, and death. A lunar crater also honors him.

Joseph F. MacDonnell

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Boss, Benjamin

Born **Albany, New York, USA, 9 January 1880**
Died **Albany, New York, USA, 17 October 1970**

American astronomer Benjamin Boss was noted for his star catalogs and for work in astrometry, the precise determination of stellar positions and motions.

Son of the astronomer **Lewis Boss**, the director of the Dudley Observatory in Albany, New York, Benjamin was educated at the Albany Academy. He was awarded his bachelor's degree from Harvard University in 1901, returning to Dudley as an assistant astronomer. In 1905, Benjamin Boss took a position at the United States Naval Observatory, Washington, and from 1906 to 1908 he ran its observing station at Tatuila, Samoa. While in the South Pacific, Boss organized an expedition to Flint Island to observe the 1908 total eclipse of the Sun. Thereafter, Boss returned to Dudley Observatory, where he was appointed secretary, Department of Meridian Astronomy, Carnegie Institution, Washington, serving in this post until 1912. The department was affiliated to Dudley Observatory, the latter institution carrying on star cataloging work financed by Andrew Carnegie.

In 1912, Benjamin Boss was named acting director of Dudley Observatory, taking over from his late father; in 1915 he became director of both Dudley Observatory and the Department of Meridian Astrometry. In that same year, Boss began serving as editor of the *Astronomical Journal*, a position he held until 1941 when Dudley turned this publication over to the American Astronomical Society. (The *Astronomical Journal*, founded in 1849 by **Benjamin Gould**, is the oldest American periodical devoted to reporting astronomical research.)

Boss made valuable contributions early in his career to the study of the motions of stars in the Milky Way Galaxy. Nineteenth-century astronomers had generally supposed that stellar motions were essentially random (apart from systematic streaming due to the motion of the Solar System). Work around 1900 by **Jacobus Kapteyn**, **Arthur Eddington**, **Frank Dyson**, and **Karl Schwarzschild** revealed definite systematic motions that we now attribute to the rotation of the galactic disk within a nonrotating stellar halo. Kapteyn described the phenomenon as star streams, Schwarzschild as a velocity ellipsoid. Both the Bosses initially opposed the idea, though the elder Boss had actually discovered one systematic motion (that of the stars of the Hyades cluster, from which their distances can be determined), and his 1910 catalog had data later used to support star streams in general. The younger Boss soon changed his mind when he himself found asymmetries in the motions of the stars with the largest apparent motions on the sky (the ones that do not share disk rotation) and recognized several additional moving groups of stars like the Hyades but more distant.

Benjamin Boss spent the vast majority of his professional career reducing data for and compiling the massive *General Catalogue of 33,341 Stars for the Epoch 1950.0*, which was published by the Carnegie Institution in 1937. Lewis Boss had first conceived of this project in the 1880s. The *General Catalogue* incorporated data from two earlier Dudley catalogs of southern and northern stars and 238 other star catalogs dating back to 1755. In addition to selecting data critically, the younger Boss developed sophisticated methods for giving more weight to more reliable data and taking systematic errors into account. He and his staff put almost three decades (1910–1937) and 300–700 "computer years" of effort into the *General Catalogue*, which remained unrivaled in its number of accurate positions and proper motions well into the 20th century. It was one of the first star catalogs keypunched into machine-readable format. (The Dudley Observatory "computers" differed from the women who did data analysis and processing at Harvard, Lick, Yerkes, and Mount Wilson observatories in being almost exclusively women who had only a high-school education at best, while the other observatories tended to employ women who had received college degrees.) Boss retired from the directorship in 1956.

Peter Wlasuk

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Boss, Lewis

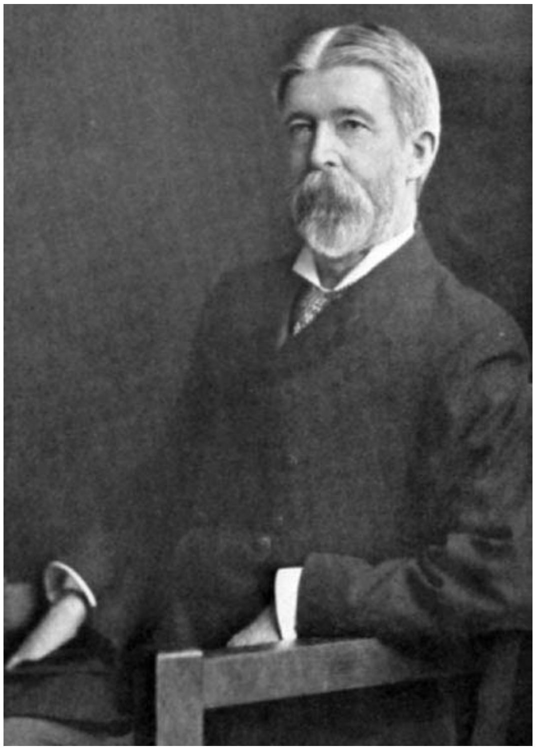
Born **Providence, Rhode Island, USA, 26 October 1846**
Died **Albany, New York, USA, 5 October 1912**

Astrometrist Lewis Boss directed the Dudley Observatory (Albany, New York), was responsible for the production of four independent star catalogs, and edited the *Astronomical Journal*.

Boss, son of Samuel P. and Lucinda (*née* Joslin) Boss, was educated at Dartmouth College and received his A.B. in 1870. Boss's formal training in astronomy was limited to a single course taken under **Charles Young**. Yet, he learned to use astronomical instruments and to reduce his observations through visits made to the Dartmouth College Observatory. Boss deepened his interest in astronomical matters while working as a clerk in the government land office at Washington, DC. Concurrently, he secured the loan of various instruments from the United States Naval Observatory.

In 1871, Boss married Helen Hutchinson; the couple had four children. One of them was the astronomer **Benjamin Boss**.

In 1872, Boss joined the United States Northern Boundary Commission survey of the 49th parallel (separating Canada and the United States) as assistant astronomer. He was charged with establishing the latitudes of stations from which surveyors operated. Boss



improved contemporary latitude determinations by eliminating systematic errors caused by faulty observations and methods of reduction. From these labors, Boss compiled a catalog (1878) of the declinations and proper motions of 500 stars that was adopted by the *American Ephemeris* in 1883.

Appointed director of the Dudley Observatory in 1876, Boss remained in that position for the rest of his life. A major project during his tenure was the observation and reduction of star positions for a zone (+1° to +5° declination) of the *Astronomische Gesellschaft Katalog*. Boss kept his probable errors well within the limits expected for this catalog. A comparison of his results with earlier observations induced the Carnegie Institution of Washington to appoint Boss as the head of its department of meridian astrometry in 1906.

Boss's work led to numerous scientific papers and four other important star catalogs. These are Boss's *Preliminary General Catalogue* (1910); the *San Luis Catalogue* (1928), based on observations by Boss and his son, Benjamin, with the Dudley Observatory's meridian circle temporarily sited in Argentina; the *Albany Catalogue* (1931); and the *General Catalogue* (1937), which contains positional data and proper motions of 33,342 stars brighter than 7.0 magnitude.

Boss also determined the orbits of several comets, observed the total solar eclipse of 29 July 1878, and headed the government expedition to Santiago, Chile, to photograph the 1882 transit of Venus. In 1893, he moved the Dudley Observatory to a more favorable location at Albany, New York. Four years later, he became associate editor, and in 1909 editor, of the *Astronomical Journal*. During his lifetime, Boss received honorary doctorates from Union College, Syracuse University, and Dartmouth College.

For his "long-continued work on the positions and proper motions of fundamental stars," Boss was awarded the Gold Medal of the Royal Astronomical Society (1905), the Lalande Prize of the French Académie des sciences (1911), and membership in the National Academy of Sciences. Boss's papers are preserved at the Dudley Observatory Archives, Schenectady, New York.

Richard Baum

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Bouguer, Pierre

Born **Le Croisic, (Loire-Atlantique), France, February 1698**
Died **Paris, France, 15 August 1758**

Pierre Bouguer was the inventor of the photometer, the heliometer, and the metacenter. He was also an hydrographer, an astronomer, and the father of naval architecture.

Bouguer was one of three children of Jan Bouguer and Marie Françoise Josseau; he was baptized on 10 February 1698. His father was a navigator, but lost a leg in battle and received the certificate of *Maîtrise d'hydrographe*. In June 1691, Jan Bouguer took charge of the new École d'hydrographie in Le Croisic. In the year Pierre was born, Jan published a navigation treatise.

Pierre was among his father's pupils at the school. When his father died in 1714, Bouguer was a student in the Jesuit school in Vannes. He applied to succeed his father, went to Brest, and successfully passed the examination to become the *Maître d'hydrographie du Roy* at Le Croisic. The research he performed alongside his teaching was noticed, and in 1730 Bouguer was called to Le Havre, then the most important harbor on the English Channel. At Bouguer's request, his Le Croisic post was given to his brother Jean.

In 1727, Bouguer was awarded a special prize, given by the Académie royale des sciences, for the best way to mast ships. In 1729 and 1731 he obtained similar prizes for determining the altitude of celestial bodies at sea and for the art of determining the orientation of the compass. At the same time he published his *Essai d'optique sur la gradation de la lumière*. All of this brought Bouguer to the attention of the Parisian scientists: In 1731, while still residing in Le Havre, he became an associate geometer of the academy, and soon a full member.

Bouguer was selected to be part of the expedition to travel close to the Equator (Peru) to decide between **Isaac Newton** and **Giovanni** and **Jacques Cassini**, on the Earth's shape. He embarked at La Rochelle in May 1735 having with him, among other instruments, an octant newly made for navigational aids from **John Hadley**'s design. This expedition, under **Louis Godin**, would take 10 years. Accompanying Bouguer were also **Charles La Condamine** and two Spanish officers, Jorge Juan and Antonio de Ulloa. This trip had important consequences for Bouguer and his scientific work. Four of the men returned to France, with results favoring Newton, while Godin pursued a career in Spain, dying there. The quality of the data, much better than that of the Lapland expedition under **Pierre de Maupertuis**, allowed **Jean-Baptiste Delambre** and **Pierre Méchain** to employ it for their determination of the length of the meter in 1799. The measurements were made according to the *Toise du Pérou* they brought with them in Equador. Difficulties between Bouguer and La Condamine resulted in several publications, by Bouguer in 1744 and in 1746 (later in 1754) followed by La Condamine in 1751.

In his free time, Bouguer pursued ideas he had during the expedition. He had previously studied refraction, publishing a memoir in 1729. He completed this work in 1737, leaving his name on Bouguer's law, considered valid for a half-century.

Bouguer developed *force de la lumière*, the subject now known as photometry. His *Essai d'optique sur la gradation de la lumière* was published in 1729, but the photometer (he called it a *lucimètre*) came 10 years later. From this work came two of Bouguer's laws, one being related to the degree of illumination variations, the other one linked to the logarithmic scale, leading to the *droite de Bouguer*. His *Traité d'optique sur la gradation de la lumière*, in its definitive form, was posthumously published by his friend **Nicolas de La Caille** in 1760.

In 1747/1748 Bouguer designed a new instrument that he called an *héliomètre* to measure diameters of the Sun and of the Moon, experimenting with it during the following year. The more successful idea of **John Dollond** in England (1753), of making a two-part achromatic objective instead of two full lenses set close together by Bouguer, was more efficient. Nonetheless, the great success of the heliometer was the first measurement of an accurate stellar parallax by **Friedrich Bessel**, in 1838.

From the Peruvian expedition, Bouguer also brought back results on the deflection of the plumb line, mostly influenced by the mountains; he mentioned it in 1754 and in 1756, resulting in the adoption of the term Bouguer anomaly, a phenomenon studied by others later. Bouguer also pursued studies on the Earth's rotation. As an hydrographer, he carried out research into naval science, leading to a number of publications including *De la mâture des vaisseaux* … (1727), *Traité du navire, de sa construction et de ses mouvements* (1746), *Nouveau traité de navigation* … (1753), and *De la manœuvre des vaisseaux* … (1757). The most important was the 1746 volume, recounting Bouguer's travels on the Atlantic and to Peru, as well as developing a number of important ideas about shipbuilding.

Shipbuilding at the time was in the hands of marine carpenters, who kept their methods secret. In dealing with the stability of a ship, Bouguer posited the notion of the *métacentre*, a theoretical point situated above the center of buoyancy. So long as the metacenter is also above the ship's center of gravity, buoyancy can restore equilibrium; if the metacenter is below the center of gravity, capsizing can occur. The book was translated into English, appearing as *A Treatise on Ship-building and Navigation* … .

Suzanne Débarbat

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Boulliau, Ismaël

Born **Loudun, (Vienne), France, 28 September 1605**
Died **Paris, France, 25 November 1694**

An early Copernican and Keplerian, Ismaël Boulliau was the most noted astronomer of his generation. The first surviving child of Calvinist parents, Ismael Boulliau (1583–1625), a notary and city official, and Susanna Motet (1582–1634), Boulliau began his studies in humanities at Loudun and after taking a law degree at Poitiers, he completed his studies in philosophy at Paris. Following his father's death in 1625, Boulliau converted to Catholicism and moved permanently to Paris in 1632. During the next 30 years Boulliau enjoyed the patronage of the family De Thou and assisted the brothers Dupuy at the Bibliothèque du roi, home of the famous *Cabinet Dupuy*. Here Boulliau made lifelong friends with **Pierre Gassendi** and **Marin Mersenne**, met with **René Descartes**, Gilles Roberval, and Blaise Pascal, and established long-term relationships with learned visitors – among them **Johannes Hevelius**, Henry Oldenburg, and **Christiaan Huygens** – many becoming major correspondents.

Although he published numerous books and traveled widely in Holland, Germany, Poland, Italy, and the Levant Boulliau's reputation as astronomer, mathematician, and classical scholar was largely due to his correspondence network. A pivotal figure in the Republic of Letters, Boulliau extended the humanist tradition of *intelligencer* to the New Science. His correspondence network, which rivaled the combined efforts of Mersenne and Oldenburg, tells us much about the New Science – much about the reception of **Nicolaus Copernicus**, **Johannes Kepler**, **Galileo Galilei**, Descartes and much about the complex communities that gave science shape.

Boulliau inherited an interest in astronomy from his father. Good evidence suggests Boulliau made astronomical observations by the age of 12, became enamored with astrology in adolescence, and by age 20 converted to Copernicanism. Mersenne proclaimed that Boulliau, by age 30, was "one of the most excellent astronomers of the century." When Boulliau reached the age of 45, Gassendi bestowed upon him the singular title "premiere astronomer of the century." Nominated *astronomus profundæ indaginis* by **Giovanni Riccioli** in 1651, Boulliau enjoyed a remarkable reputation throughout his career. Since that time, however, his contributions have been viewed more critically. While he acknowledged Boulliau's historical importance, **Jean-Baptiste Delambre**, for example, dismissed Boulliau's planetary theory as ingenious but useless, concluding that it was a "retrograde step" for science. Similar views – still linked to the "retrograde" metaphor – have appeared in more recent works.

From the beginning of his career Boulliau sought to reform and restore astronomy. This meant improving astronomical tables and perfecting the principles of planetary motion. Despite his much-discussed Platonism, Boulliau believed this reformation required fresh – not necessarily new – observations. Boulliau began by applying his skills as a classical scholar, by unearthing ancient observations of the Egyptians, Babylonians, Greeks, and others. His strategy–at once historical, empirical, and mathematical – was to establish a long base line of observations, and from these "general circumstances" of planetary motion, to determine their mean motions, thus exposing their deepest uniformities and most subtle inequalities.

In addition to his historical studies, Boulliau was a dedicated observer, maintaining detailed records from 1623 to 1687. Over the course of his career, Boulliau owned several of the best telescopes in Europe. More valuable than "diamonds and rubies," they included an 11-ft. telescope, given to him by the Grand Duke of Tuscany in 1651, and later, thanks to friends, he obtained lenses from Huygens (a 22-ft. in 1659), T. L. Burattini (10- and 12-ft. in 1666), and **Giuseppe Campani** (1670). Active for over 60 years, Boulliau's long-term interests, beyond the usual concern for eclipses and conjunctions, focused on the variable star Mira Ceti and lunar libration – Boulliau called the Moon's second (synodic) inequality "evection," a term still in use. Although he was not a first-rate observer, Boulliau was unrivaled in the Republic of Letters for coordinating astronomical observations, communicating data, and comparing results.

Despite his passion for observation, Boulliau is best remembered as a theorist. An outspoken Copernican and critical student of Kepler, Boulliau's first book in astronomy aimed to supply new arguments for the motion of the Earth based on "Astronomy, Geometry, and Optics" and not "physical conjecture." Although his *Philolaus* (Amsterdam, 1639) was published anonymously, the author was never in doubt, as Boulliau's manuscript (*De motu telluris*, 1634) had circulated privately in the years immediately following Galilei's condemnation. When the book finally appeared, it exerted an immense influence, spawning controversy across Europe that ranged from praise and envy to anger and rage.

Boulliau's *magnum opus* appeared 6 years later. Arguably the most important work on planetary systems between Kepler and **Isaac Newton**, the *Astronomia philolaïca* (Paris, 1645) clearly extended awareness of planetary ellipses. Here Boulliau offered an entirely new cosmology, a "newer than new" alternative to Kepler's *Astronomia nova*. Boulliau began by attacking Kepler's cosmology at its very foundation, systematically undermining the physical principles on which Kepler based his calculations. Boulliau concluded that Kepler's celestial physics and calculational procedures were conjectural and cumbersome, unworthy of Kepler's genius. Critical of Kepler's assumptions and conclusions, Boulliau embraced elliptical orbits but insisted they could not be demonstrated by calculation alone. In place of Kepler's *anima mortrix* and "celestial figments," Boulliau argued it was simpler to assume that planets were self-moved, that their motion, imparted at creation, was conserved. In place of Kepler's indirect "a-geometrical methods" Boulliau proposed direct calculation based on mean motion.

Boulliau's solution to the "problem of the planets" was the conical hypothesis (1645). Because circles and ellipses are conic sections, Boulliau imagined that the planets moved along the surface of an oblique cone, each revolving in an elliptical orbit around the Sun located at the lower focus. By construction, the axis of the cone bisected the base, which at once defined the upper (empty) focus of the ellipse as well as an infinite number of circles parallel to the base. The position of a planet on the ellipse at any given time (Kepler's problem) was thus defined by an intersecting circle, and hence, at any given instant, the motion of the planet was uniform and circular around its center (**Plato**'s *Dictum*). Where Kepler invoked a complex interplay of forces, Boulliau explained elliptical motion by reason of geometry; the planets naturally accelerated or decelerated due to the differing size of circles. Where Kepler employed indirect trial-and-error methods based on physics, Boulliau provided direct procedures based on geometrical principles. In context, Boulliau's conical hypothesis was elegant and practical. Kepler's construction – by contrast – was ingenious but useless.

The foundations of Boulliau's cosmology, however, were soon called into question – the result was the "Boulliau–Ward debate." Prompted by Sir Paul Neile, **Seth Ward** published several treatises (1653; 1656) attacking Boulliau. Here Ward claimed to offer not only a more accurate alternative to the conical hypothesis (the "simple elliptical" model) but also to demonstrate that the two models were *geometrically* equivalent. Boulliau responded with his *Astronomia philolaica fundamenta clarius explicata* (Paris, 1657). After acknowledging his error, noted earlier in his *Philolaic Tables* (1645), Boulliau shrewdly turned the tables against Ward. The *real* error, Boulliau maintained, belonged to Ward, who erroneously identified the conical hypothesis with his "simple elliptical" alternative, that is, an ellipse where the empty (nonsolar) focus served as an equant point. The two hypotheses were not, in fact, *observationally* equivalent. If Ward's model were applied to the planet Mars, it would result in a maximum error of almost 8′ in heliocentric longitude, not the 2.5′ calculated from the conical hypothesis. Ward failed to note the difference; Delambre, a century later, repeated the error. Boulliau then supplied a more refined model, the "modified elliptical" hypothesis. Boulliau compared the new model with Kepler's calculations (using the same Tychonic data) and found it more accurate, having reduced the error to less than 50 arc seconds, clearly within the limits of observational error. If the issue was empirical accuracy and ease of calculation, Boulliau had clearly won the day.

Boulliau's reputation reached its zenith during the 1660s in England. Cited in learned works and the popular press, Boulliau's name was widely linked to mathematical models and various astronomical tables. But his vision of a New Cosmology was lost. During this time Boulliau's *Philolaic Tables* were widely copied, adapted, or imitated. In England, **Jeremy Shakerley**, among others, believed they were more accurate than Kepler's, while in Italy, Riccioli demonstrated the claim for Saturn, Jupiter, and Mercury. Boulliau's modified elliptical hypothesis also received accolades. Although he had proposed his own method, **Nicolaus Kauffman** (Mercator) continued to praise Boulliau's model, claiming it could hardly be improved for accuracy. Not least, the "Ornament of the Century" offered praise. In his *Principia* (1687, Bk. III) Newton claimed that Kepler and Boulliau "above all others" had determined the periodic times of the planets with greatest accuracy. As the century drew to a close, Boulliau's reputation – by all appearances – had yet to undergo its "retrograde" phase.

Robert Alan Hatch

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Bour, Edmond

Born **Gray, Haute-Saône, France, 19 May 1832**
Died **Paris, France, 9 March 1866**

Edmond Bour was a professor and mathematician who contributed to celestial mechanics. Bour, the son of Joseph Bour and Gabrielle Jeunet, entered the École Polytechnique in 1850, graduating first in his class in 1852. He then moved to the École des mines. On 5 March 1855, Bour presented "On the Integration of Differential Equations of Analytical Mechanics" to the Academy of Sciences; a shortened version of the work appeared in J. Liouville's *Journal of Pure and Applied Mathematics*. In July of that year, he was appointed professor of mechanics and mining at the École des mines at Saint-Étienne.

Back at the Paris École des mines, Bour presented two theses on 3 December 1855. One concerned the three-body problem, the other the theory of attraction. In 1859, he became a lecturer on descriptive geometry in Paris, a post he held until the next year when he became a professor at the École des mines. Then in 1861, he became a professor of mechanics at the École Polytechnique. In 1862, Bour was a candidate for membership in the Academy of Sciences, but he lost to Pierre-Ossian Bonnet.

In 1858, the prize question in mathematics for the Academy of Sciences concerned the differential equations resulting when any surface is pressed against a given surface. Of five papers submitted, the judges agreed that three provided adequate solutions, but Bour was awarded the prize for his masterful analysis of the case where the given surface was itself a solid of revolution. The judges hoped that he would generalize his analysis but unfortunately Bour could not extend the work, dying of an incurable disease.

Christian Nitschelm

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Bouvard, Alexis

Born **Contamines, (Haute-Savoie), France, 27 June 1767**
Died **Paris, France, 7 June 1843**

Alexis Bouvard was a French astronomer who first suggested that perturbations to Uranus' motion might be caused by an unseen planet. Bouvard was a penniless rural youth who, in 1785, made his way to Paris where he took mathematics lessons to be able to make a living as a calculator. He attended free courses at the Collège de France. His passion for astronomy was ignited by visits to the Paris Observatory, where he was soon admitted as a student-astronomer in 1793. Within 2 years, he was promoted to astronomer.

Bouvard met **Pierre de Laplace** in 1794 just as the *Mécanique céleste* was being composed. Laplace gave him the task of doing the detailed calculations for the work. With Laplace as patron, Bouvard gained a position at the Bureau des longitudes in 1794. He spent the rest of his career there, providing tables for *Connaissance des temps* and the *Annuaire* of the bureau. At the observatory, he was an indefatigable observer, discovering comets in C/1797 P1, C/1798 X1, C/1801 N1 (discovered a night earlier by **Jean Pons**), and C/1805 U1. When comet 2P/1818 W1 appeared, he calculated an orbit for the bureau and realized it was the same as that for the comet of 1805, later to be called comet 2P/Encke. During this period he also worked on lunar theory, which garnered a prize from the Institut de France in 1800.

In 1808, Bouvard published his *Tables astronomiques*, which provided tables for the orbits of Jupiter and Saturn. When revising the work (for publication in 1821), Bouvard wanted to include tables for Uranus. Even though he had a few prediscovery sightings, mostly thanks to the work of **Pierre le Monnier**, Bouvard could not fit an orbit using Laplace's methods, so based his tables on post-discovery positions. Within a few years, it was clear that Bouvard's tables were not predicting accurate locations. He believed that there must be a perturbing body. He asked his nephew, Eugène Bouvard, then a student-astronomer at the Paris Observatory, to follow up on this idea, but the latter resigned in 1842 and Bouvard himself was dead the next year. It was, however, the mismatch of Bouvard's predictions and actual observations of Uranus that led **John Adams** and **Urbain Le Verrier** to predict the position of Neptune in 1846.

Bouvard was elected to the Académie des sciences in 1803, and the Royal Society of London named him a fellow in 1826.

Richard A. Jarrell

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Bowditch, Nathaniel

Born **Salem, Massachusetts, (USA), 26 March 1773**
Died **Boston, Massachusetts, USA, 16 March 1838**

Nathaniel Bowditch was already well recognized for his original contributions to astronomy when he translated, corrected, and annotated the first four volumes of **Pierre de Laplace**'s *Méchanique céleste*. His translation, published and distributed at his own expense, provided a foundation for American physical astronomy in the 19th century.

The fourth of seven children of Habakkuk and Mary (*née* Ingersoll) Bowditch, Nathaniel's formal education stopped at the age of 10 when straitened financial conditions of the family forced him to go to work in his father's cooperage. By 1785, Bowditch had learned the rudiments of accounting and entered a 9-year contract of indentured service as a clerk with a ship's chandler. Living and working in the chandlery, he benefited from access to the owner's extensive library, from which he continued to educate himself, learning Latin and mathematics while working as a clerk. He also benefited from a peculiar set of circumstances: In 1780, the *Pilgrim*, a privateer based at Beverly, Massachusetts, captured a ship whose cargo included the scientific library of the Irish chemist Richard Kirwan. Among the 115 books captured were works of **Isaac Newton**, **Daniel Bernoulli**, **Johann Bernoulli (III)**, and **Jacob Bernoulli**, and E. Chambers's *Cyclopedia; Or an Universal Dictionary of the Arts and Sciences*. The *Pilgrim* arrived in Salem in 1781 and auctioned its cargo; the books were bought by a local apothecary who intended to use the pages for wrapping paper. This dreadful fate was avoided when a group of citizens raised funds to buy the books and donate them to the newly founded Salem Philosophical Society. This gave Salem the best scientific library north of Philadelphia. The books were housed in the home of Reverend John Prince, who allowed the 18-year-old Bowditch to access the library in 1791. In 1793, Bowditch discovered an error in Newton's *Principia*.

After completing his contractual service at the chandlery, Bowditch assisted with a survey of Salem and taught himself the mathematics and practice of navigation. Soon thereafter, Bowditch traded the sedentary life ashore for the life at sea, making one voyage as a clerk and then three voyages as a supercargo between 1795 and 1799. Between his first and second voyages in March 1798, Bowditch married Elizabeth Boardman; she died 7 months later while he was at sea.

On his first voyage, Bowditch was also the second mate of the crew with responsibility for navigation. As he checked through the available reference tables in the 13th English edition of John Hamilton Moore's *The Practical Navigator*, he discovered mistakes in the tables that could result in serious navigation errors. Furthermore, the tables were incomplete, and Bowditch designed additional tables that would simplify calculations and make the volume easier to use at sea. It was also on this first voyage that Bowditch conceived of a simplified but more accurate procedure for determining the local time from the Moon, the navigational technique known as "method of lunars." He began using this technique and found it gave more accurate results. The method of lunars allowed mariners to determine their longitude by observing the position of the Moon to determine the local time. Though accurate marine chronometers had been built by John Harrison between 1735 and 1759, they were as yet too expensive for use by merchant sailors, who relied instead on observations of celestial phenomena (such as the position of the Moon) in order to determine local time.

At the end of his first voyage, Bowditch provided a list of these errors to Edmund M. Blunt, the distributor of Moore's *Practical Navigator.* He advised Blunt of his ideas to correct and supplement both the tables and the text of the *Practical Navigator* and provided him with a tabulation of some of the errors he had already discovered. Blunt was enthusiastic, and they agreed to undertake the creation of a new practical navigator. Blunt published a new edition, titled *The American Practical Navigator*, in 1799 with Bowditch's first round of corrections. On his second voyage Bowditch continued to find errors, and a second corrected edition of the *American Practical Navigator* was published. After the third voyage, Bowditch was ready with his completely revised edition including the new method of lunars, many supplemental tables, and other innovations, which Blunt published in 1802 as *The New American Practical Navigator* with Bowditch as the author. In total, Bowditch had compiled a list of over 8,000 errors in the tables of Moore's *The Practical Navigator*. It is small wonder that "the Bowditch" as it came to be known, developed a reputation for its reliability and was the standard reference for navigators for more than a century.

In 1800, Bowditch married a cousin, Mary Ingersoll, who was 8 years younger. They had eight children.

In 1802, Bowditch became part owner and master of a merchant ship. His fifth voyage, to Sumatra in November 1803 (during which Bowditch read the first volume of Laplace's monumental *Méchanique céleste),* would be Bowditch's last trip. He gave up the sea to become an insurance executive at the Essex Fire and Marine Insurance Company in Salem. His mathematical experience served Bowditch well in this new environment in which actuarial skills were highly valued and profitable. He was elected president of the firm in 1804.

In the early morning of 14 December 1807, a meteor streaked across the skies of New England. Bowditch compiled the observations of many individuals who had seen the meteor and estimated the meteor to have traveled at 3 miles/s along a path 18 miles high.

Bowditch also published papers on the oblateness of the Earth, the orbits of comets, errors in solar tables, and the motion of a pendulum suspended from two points. Bowditch was the first to investigate the curves traced out by such a pendulum, which are now well known as the Lissajous curves of acoustics and electronics. These papers established Bowditch as one of the preeminent figures in American science, and earned him recognition by European scientific societies. In 1818, he was elected a fellow of the Royal Society of London; in 1829 Bowditch was the first American to be elected a foreign associate of the Royal Astronomical Society.

Harvard offered Bowditch its chair of mathematics and physics in 1806; West Point made a similar offer, as did the University of Virginia (1818). Bowditch declined them all – an academic position would have necessitated too great a cut in salary. But it would have been nearly impossible for Bowditch – a prominent Federalist and scholar – to avoid a connection with Harvard, a prominent school supported by many Federalists. In 1810, he became one of the university's overseers, and in June 1826, one of its trustees.

At that point, Harvard was in dire financial straits. An internal audit ordered by Bowditch turned up a number of accounting irregularities. Bowditch forced many changes in the name of fiscal responsibility, which brought him into conflict with Harvard's president, John Kirkland. In one noteworthy encounter, Kirkland defended the competence of a mathematics professor about to be dismissed. Bowditch's assessment was that "Peirce of the sophomore class" was a better mathematician than the professor. The Peirce involved was none other than **Benjamin Peirce**, who would himself become a professor at Harvard in 1833, and go on to help establish the Harvard Observatory. When Kirkland eventually resigned, the students – with whom Kirkland was very popular – lambasted Bowditch.

Bowditch's best-known work is a translation of Laplace's monumental *Méchanique céleste* into English. But Bowditch did much more than translate Laplace: He added a great deal of commentary to make the work more comprehensible, filling details dismissed by Laplace with a glib "It is easy to see …" He corrected many mistakes in Laplace's work, and provided citations to the sources that Laplace had relied upon but had failed to credit. Bowditch's effort was similar to that of **Mary Somerville**'s *The Mechanism of the Heavens* but was more comprehensive. The publication of the translation was delayed by many years due to a lack of funding. Though the American Academy of Arts and Sciences offered to pay for the publication by soliciting private donations, Bowditch refused to accept their offer, and eventually paid for publication at his own expense. This cost was nearly $12,000 – a third of his personal fortune. The first four volumes would appear in 1829, 1832, 1834, and 1839. Bowditch died of cancer partway through the translation of the fifth volume.

Jeff Suzuki

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Bowen, Ira Sprague

Born **Seneca Falls, New York, USA, 21 December 1898**
Died **Los Angeles, California, USA, 6 February 1973**

American spectroscopist Ira Bowen is eponymized in the Bowen fluorescence mechanism, which accounts for the anomalously large strength of a few emission features of oxygen and nitrogen in gaseous nebulae. His most important contribution was the recognition that certain other lines in these nebular spectra were produced by improbable transitions (but different ones) also of oxygen and nitrogen, rather than by a hypothetical "nebulium."

Ira Bowen was the son of Philinda Sprague and James Bowen (Pastor of the local Wesleyan Methodist Church) and educated at Houghton Seminary and Oberlin College (A.B.: 1916; Sc.D.: 1948). He began graduate work at the University of Chicago, where he was strongly influenced by **Albert Michelson** and **Robert Millikan**, the latter in effect taking Bowen with him to the California Institute of Technology as an instructor in 1921, his graduate work unfinished. Bowen received a Caltech Ph.D. in 1926 for work in vacuum ultraviolet spectroscopy. He also contributed to high-altitude measurements of cosmic rays. Caltech appointed Bowen to its faculty as soon as he ceased to be a graduate student (assistant professorship, 1926; associate professorship, 1928; and full professorship, 1931), and the work for which he is remembered was done there.

In 1946, the trustees of the Carnegie Institution of Washington appointed Bowen director of Mount Wilson Observatory as successor to **Walter Adams** – an unusual choice, given his background in laboratory spectroscopy. With the establishment of Palomar Mountain Observatory in 1948, and with its headquarters in the same Pasadena building, he became director of both, eventually under the name Hale Observatories (named for **George Hale**). Bowen retired in 1964, having held firm throughout to the rule that women astronomers could not be assigned observing time at either place, leaving it to his successor (**Horace Babcock**) to welcome the first official women observers.

Soon after taking up his assistant professorship, Bowen solved a 60-year-old conundrum. **William Huggins** had been the first astronomer to look at the spectra of a large number of diffuse nebulae and found that some of them emitted only discrete wavelengths and so must consist largely of ionized gas. He was able to identify hydrogen, and at one time thought that the bright pair of green lines at 5007 Å and 4959 Å was produced by nitrogen. When much larger collections of laboratory spectra of many elements provided no identification, Huggins coined the name "nebulium" (by analogy with **Norman Lockyer**'s "helium" for the element producing particular features in the solar spectrum). The main part of the periodic table was closed with hafnium (1923) and rhenium (1925), and they were not the cause either, leading contemporary astronomers to the conclusion that the green lines must come from some familiar element, but under very nonterrestrial conditions, for instance extreme low density, according to **Henry Norris Russell** and others.

Bowen had read about this puzzle, and knew enough both about ultraviolet spectra of atoms and about early quantum mechanics to be able to conclude in 1927 that the "nebulium" lines were emission from twice-ionized oxygen raised into an excited state by collisions with other atoms and deexciting only after a very long time, because the transition required the outgoing light particle (photon) to carry an unlikely (though not impossible) amount of angular momentum. These transitions and the lines they produce are called "forbidden," though in fact they are only disfavored, so that a laboratory sample of gas is never large enough to radiate a detectable amount of the line before the atoms get deexcited by other collisions. Bowen and other investigators subsequently identified forbidden (in this sense) lines of singly ionized and neutral oxygen, ionized nitrogen, ionized sulfur, and several ionization states of neon and argon in the spectra of planetary nebulae and supernova remnants like the Crab Nebula.

In 1938, Bowen visited Lick Observatory, obtaining a number of spectra of planetary nebulae in cooperation with **Arthur Wyse**, using a new spectrograph of his own design. A few permitted lines of twice-ionized oxygen seemed to be relatively much stronger than they were in the laboratory, as were two lines of doubly ionized nitrogen. Bowen was able to explain these anomalies as being due to strong lines of hydrogen and helium exciting the O[III] and N[III] atoms to levels that would otherwise only be sparsely populated. Thus, the lines emitted when the atoms fell back out of these particular levels were unusually strong. This is Bowen fluorescence, and there are other examples elsewhere in astronomical spectroscopy.

In the 1930s, Bowen played a major role in the optical design of the 200-in. telescope on Palomar Mountain as well as other optical equipment. Bowen built a novel device, called an image slicer, which placed the spectra of successive strips across an extended object side-by-side upon the photographic plate. This invention enormously increased the efficiency of observations of gaseous nebulae. As director of the Mount Wilson Observatory from 1946 to 1948, and of the combined Mount Wilson and Palomar observatories from 1948 to 1964, he directed the completion of the 200-in. Hale telescope and 48-in. Schmidt telescope and designed many of their instruments. Bowen also initiated baking photographic plates to improve their sensitivity. During World War II he was in charge of photographic work on the rocket project at the Jet Propulsion Laboratory.

Bowen received many honors. He was a Gold Medallist (1966) and Halley Lecturer of the Royal Astronomical Society and an H. N. Russell Lecturer (1964) of the American Astronomical Society. Also, he received the Ives Medal (Optical Society of America, 1952), Draper Medal (National Academy of Sciences, 1942), Potts Medal (Franklin Institute), Rumford Prize (American Academy of Arts and Sciences, 1949), and the Bruce Medal (Astronomical Society of the Pacific, 1957). He was a member of the National Academies of Sciences of the USA, of Sweden, and of India and received honorary degrees from Oberlin College, Lund University, and Princeton University. A lunar crater is named for him.

Ira Bowen and Mary Jane Howard were married in 1929; they had no children.

Most of Bowen's papers (1916–1961) are at the California Institute of Technology (Huntington Library and Caltech Archives). These include manuscript articles and speeches, and biographical material. The Center for History of Physics at the American Institute of Physics has a manuscript autobiography, some correspondence, and an oral history interview of Bowen.

Y. P. Varshni

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Bower, Ernest Clare

Born **1890**
Died **1964**

American astronomer Ernest Bower calculated one of the first independent orbits of Pluto, shortly after that planet's 1930 discovery by Lowell Observatory's **Clyde Tombaugh**.

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Boyer, Charles

Born **Toulouse, Haute-Garonne, France, 28 July 1911**
Died **Toulouse, Haute-Garonne, France, 21 August 1989**

The French magistrate Charles Boyer, observing Venus from 1957 to 1960 at Brazzaville, French Congo (now Corgo, former Zaire), took sequences of photographic plates with ultraviolet [UV] filters. He noted a 4-day recurrence in the apparition of dark features. The data was complemented by observations with astronomer Henri Camichel at Pic du Midi Observatory. A 4-day retrograde rotation of the upper Venusian atmosphere was demonstrated. The discovery was later confirmed by the Soviet Venera 8 entry probe, which, in 1972, detected directly a westward 100 m/s wind at an altitude of 55 km. It was also confirmed by the American Mariner 10 craft, which, in February 1974, took a movie of several days duration in UV light during approach, showing the planetary atmosphere turning in 4 days retrograde. Boyer was elected to International Astronomical Union Commission 16 on the Physical Study of Planets and Satellites.

Audouin Dollfus

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Bradley, James

Born **Sherbourne, Gloucestershire, England, March 1693**
Died **Chalford, Gloucestershire, England, 13 July 1762**

James Bradley discovered the aberration of starlight. He was the third son of William Bradley and Jane Pound. On 25 June 1744, at age 51, Bradley married Susannah Peach of Chalford, Gloucestershire, England, from whom he had a daughter in 1745. His wife died in 1757.

Bradley attended the Northleach Grammar School. He received his B.A. in 1714 and M.A. in 1717 from Balliol College, Oxford. Bradley was awarded an honorary D.D. degree by Oxford in 1742 upon his appointment as Astronomer Royal. In 1718, he was elected a fellow of the Royal Society at the recommendation of Astronomer Royal **Edmond Halley**. He was also given membership in national academies of science in Berlin, Paris, Bologna, and Saint Petersburg. Bradley was ordained in 1719 and became vicar of the congregation at Bridstow, Monmouthshire.

Bradley learned astronomy from his uncle, Reverend **James Pound**, rector at Wanstead, Essex, near London, with whom Bradley frequently stayed. Young Bradley adored his uncle James, who helped support him financially, nursed him through smallpox in 1717, and ultimately fostered his love of astronomy. By the time Bradley was in his 20s, he and his uncle had formed a for-hire observing partnership. So respected were their skills that both **Isaac Newton** and Halley entrusted them on multiple occasions with observing projects. Working together, Bradley and Pound determined the positions of stars and nebulae, observed eclipses of Jupiter's satellites, and measured the diameter of Venus (with a 212-ft.-long telescope) and also the parallax of Mars. Bradley himself calculated the orbits of two comets.

Bradley resigned his vicarage in Bridstow in 1721 upon his appointment as Savilian Professor of Astronomy at Oxford, a position for which he was recommended by Newton. Given his modest annual salary of £140, Bradley could not afford to live at the university. Instead, he moved in with Pound in Wanstead and visited the Oxford campus only to deliver the required lectures. In 1724, following the death of his beloved uncle, Bradley began to observe with **Samuel Molyneux**, a wealthy amateur astronomer and member of Parliament from Kew, outside London.

Having read of **Robert Hooke**'s failed attempt to detect the annual parallax of the star γ Draconis in 1669, Molyneux asked Bradley to collaborate with him in a renewed effort utilizing a high-precision zenith telescope made by England's foremost instrument maker **George Graham**. (Detection of stellar parallax would provide observational evidence of the Copernican theory of the cosmos, wherein the Earth's orbital motion creates an annual oscillation of the stars; by this time, the Copernican theory already had a strong theoretical and mathematical foundation.) The telescope was fixed vertically to the face of a chimney in Molyneux's mansion bordering Kew Green. To accommodate its 24-ft.-long tube, holes were cut through the roof and between floors. The Kew telescope was found to be exquisitely sensitive to environmental influences: The combined body heat of three people standing nearby disturbed the air enough to set the instrument's plumb line swaying. Cobwebs had to be regularly cleared from the plumb line, lest they shift the zero mark from which all measurements were gauged. Nevertheless, Bradley determined that the telescope was capable of measuring star positions with better than 1″ accuracy.

Over 80 position measurements of γ Draconis were obtained by Bradley and Molyneux over a 2-year period commencing 3 December 1725. The observations confirmed that γ Draconis exhibits an annual 20″ oscillation from its nominal position in the sky. However, Bradley and Molyneux noted that the timing of the oscillatory movement is 3 months out of phase with that expected for a parallax shift, and the degree of movement itself is far larger than they had anticipated. In August 1727, Bradley installed a smaller, wider-field version of the Kew telescope in the house of his late uncle, in Wanstead, and continued the zenith observations of γ Draconis and other stars on his own. Even after his aunt sold the house in 1732, the new owner, Elizabeth Williams, permitted him free access to his now famous telescope. (Molyneux died unexpectedly in 1728 at age 39.)

Bradley reportedly realized the true cause of γ Draconis's annual oscillation in the autumn of 1728 during a sailing cruise on the Thames. He noted how the wind vane on the boat's mast shifted its orientation with the boat's motion, even when the wind direction had not changed – *i. e.*, the vane's orientation was influenced not only by the wind but also by the movement of the boat. Similarly, Bradley reasoned, the apparent direction from which a star's light reaches the observer is altered by the forward movement of the Earth; thus the position of the star seems to oscillate as the Earth circles the Sun. This phenomenon is known as the aberration of light. From his observations, Bradley computed the speed of light: 295,000 km/s (183,000 miles/s), which is within 2% of the modern value. Bradley also established an upper limit to the annual parallaxes of the stars he had observed: Were any parallax as large as 1″, he would have observed it with the Wanstead telescope. Thus he estimated that even the nearest stars must lie at least 400,000 times farther than the Sun.

Continuing his zenith observations for another 20 years, Bradley detected a further oscillation of star positions, by as much as 9″. This he attributed to a periodic nodding motion of the Earth's axis (nutation) stimulated by the Moon's gravitational pull. For this discovery, the Royal Society of London awarded him the Copley Medal in 1748.

In 1742, Bradley succeeded Halley as England's third Astronomer Royal and director of the Royal Observatory at Greenwich, a post he would hold for the next 20 years. Despite his ascendance, Bradley maintained his propriety: He refused the king's offer of the vicarage of Greenwich, together with its significant stipend, explaining that he could not in good conscience accept a job to which he would devote less than his full measure. Bradley found Halley's Greenwich instruments to be in disrepair. He restored them and embarked on an ambitious observing program to measure the positions of stars and determine the precise means to correct such measurements for the effects of atmospheric refraction. In 1749, he persuaded government officials to provide a grant of £1,000 with which he upgraded the Royal Observatory's equipment, including two quadrants and a transit instrument by Bird, a precision clock by Graham, and a micrometer. Between 1748 and 1762, Bradley and his assistants carried out more than 60,000 individual observations of stars. He also accurately determined the latitude of Greenwich and carried out a detailed assessment of **Tobias Mayer**'s lunar tables for determining longitude at sea.

In 1818, German astronomer **Friedrich Bessel** united Bradley's observations with his own to produce a fundamental catalog of 3,222 stars with positions accurate for the year 1755. The Bradley–Bessel compilation formed the starting point for determining the proper motions of these stars. By setting a new standard of precision in observation, Bradley can rightly be dubbed the founder of high-precision positional astronomy.

Alan W. Hirshfeld

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Bradwardine, Thomas

Born **England, *circa* 1290**
Died **London, England, 26 August 1349**

Thomas Bradwardine is chiefly known for his writings on mathematics, but may also have produced astronomical tables.

Bradwardine enters the historical record in 1321 as a fellow of Balliol College, Oxford. Two years later he migrated to Merton College, where he remained until 1335. Bradwardine became chancellor of Saint Paul's Cathedral, London, in 1337, and sometime thereafter he became chaplain to Edward III. Bradwardine preached that the English victories in the Hundred Years' War came from God's will rather than through the influence of celestial bodies. His theological masterwork, *De causa Dei*, emphasized divine action throughout creation. Bradwardine was elected archbishop of Canterbury in 1348, but King Edward quashed the election on a technicality. He received the royal assent in the following year and was consecrated archbishop on 10 July 1349, only to die of the plague 6 weeks later.

At Oxford, Bradwardine chiefly lectured and wrote on mathematical subjects, and produced the textbooks *De arithmetica speculativa* and *De geometria speculativa*. Composed in 1328, his *De proportionibus* gave an innovative treatment of velocity in terms of proportions between force and resistance; it helped shape late medieval and early modern approaches to kinematics. Bradwardine's philosophical works include *De continuo*, addressing the continuous or discontinuous nature of matter, and *Insolubilia*, concerning logical paradoxes.

Bradwardine may have compiled astronomical tables for calculating the positions of planets, but this has not been established for certain. It is certain that Bradwardine had an interest in astronomy and astrology. The astronomers **John Maudith**, **Simon Bredon**, and **William Rede** were his colleagues. Bradwardine himself owned astronomical works in manuscript. A theme in his later theological writings was the futility of astrological prediction.

Keith Snedegar

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Brahe, Tycho [Tyge] Ottesen

Born **Knudstrup, Scania, (Sweden), 14 December 1546**
Died **Prague, (Czech Republic), 24 October 1601**

Author of the Tychonic system, the great observer Tycho Brahe was raised as an only child at the home of his father's brother Jørgen Brahe, who had decided that Tycho was to have an education in law. The fields of astronomy and chemistry were not considered suitable backgrounds for the life of a nobleman. Twelve-year-old Brahe came to the University of Copenhagen and started a study and travel period that was to last for the next 12 years. He possibly observed that a solar eclipse event predicted for 1560 actually took place at the predicted time. This may have led him to begin studying astronomy on his own.

In 1562, Brahe traveled to the University of Leipzig, where he added the study of astronomy to his study of the law, and bought astronomy books and instruments. He studied with critical eyes and soon saw that only direct observation of the sky could resolve the contradictory ideas in all the learned books. In 1563, Saturn and Jupiter were in a position close to each other, and Brahe found that the ancient Alphonsine tables gave the date with an error of one entire month, whereas the new Prutenic method, calculated according to the theories of **Nicolaus Copernicus**, only had an error of a few days. Subsequently, Brahe devoted his life to a renovation of astronomy based on more trustworthy observations. His first instrument, an approximately 3-ft. long Jacob's staff, was not perfect, but, regardless, he calculated a correction table so that the results were usable.

In 1565, Brahe started on his second study trip, to Wittenberg and Rostock, Germany. It was here that during a dueling match he lost part of his nose; ever after he had to use a prosthesis. Brahe now openly studied alchemy and astrology in addition to routinely making astronomical observations. In 1568, he enrolled at the University of Basel with the intention of settling down at a later date in this town or its vicinity. Now at the age of 22, Brahe had acquired all the knowledge of chemistry and astronomy of his times. He spent most of 1569 and 1570 in Augsburg, Germany, as an astronomy assistant to the mayor of the town. Brahe was in charge of the construction of a quadrant with a radius of 19 ft., intended to be capable of measuring every arc minute. However, his experience was that an instrument that heavy and clumsy could not yield the expected measuring accuracy.

Brahe also constructed the shell of a wooden sphere with a diameter of 5 ft. Ten years later he had ensured that this globe retained its rounded form, and was marked with poles and divided into circles for reading and recalculation of celestial coordinates. After another 15 years of work, Brahe had the surface marked accurately with definite positions for 1,000 fixed stars, and this celestial globe stood as an impressive monument to his life's work. The globe traveled with Brahe to Bohemia and was later brought home to Denmark, as a war treasure, to Round Tower (in Copenhagen) where it burned in 1728.

After the death of his father in 1571, Brahe moved into the home of Steen Bille at the estate of Herrevad (in Denmark), and delved more heavily into the study of alchemy. But on 11 November 1572, in the constellation of Cassiopeia, he spotted a great wonder: a new star that we know today as a supernova. Brahe measured the star's (SN B Cas) distance from the so called fixed stars in the vicinity, and he recorded how its brightness gradually diminished. He proved that the star was situated farther from the Earth and the Moon than could be explained away as an atmospheric phenomenon; rather it must belong among the fixed stars. But this meant that the star would have appeared (in an Aristotelian view of the sky) in the region of unchangeability. That prevailing thesis had to subside in light of what this 26-year-old, well-educated astronomer had seen in the sky.

Brahe's first book, *De Nova Stella*, was published in 1573. Only after his death was Brahe's comprehensive astronomical work about the new star, *Astronomiae Instauratae Progymnasmata*, published in three volumes. The first volume included Brahe's new theories about the Sun and the Moon, as well as his revised star catalog. The second volume was about the new star, and the third volume was a critical review of the works of others about the new star.

With publication of *De Nova Stella*, Brahe's position as an astronomer had been firmly established within the learned society of Europe. The problem now was finding a suitable way of life for this nobleman researcher. In the fall of 1574, he lectured in Copenhagen about the movements of the heavenly bodies according to Copernicus' theories, but related them to a stationary Earth. In this way Brahe avoided an open conflict between traditional cosmology and the Copernican astronomy.

For most of 1575, Brahe was traveling and preparing for his emigration to Basel. First he visited **Landgrave William IV** of Hesse in Kassel, who himself was an astronomer. They embarked on a friendship that can be traced in many letters containing astronomical themes. In 1596, Brahe published his correspondence with colleagues from Kassel as the first, and only, volume of his *Epistolae Astronomicae.*

King Frederick II of Denmark offered Brahe the island of Hven, situated between Scania and Zealand and, in addition, the means for the construction of a suitable residence and observatory. Brahe agreed to the king's wishes, being attracted to the idea of a lone island that would be a haven free from the disturbance of visitors. On 8 August 1576, the cornerstone was laid for Uraniborg, built in gothic renaissance style. So from the date of his 30th birthday on 14 December 1576, Brahe could engage in routine observations and began 20 years of happy work. Uraniborg was not finished until 1580, by which time it was equipped with a laboratory basement, residence, library, and observatory. In 1584, Brahe had Stjerneborg (a sort of star castle) built, with five cupolas over corresponding vaults where the larger instruments would have a permanent place protected against the wind. The island of Hven became the home of an exemplary research institution where Brahe developed instruments, carried out a vast number of observations and calculation programs, and finished his work in the form of scientific publications.

At Hven everything was in a class by itself, including the expenses. Apart from the island being free of cost for his lifetime, a separate building subsidy, and an annual cash payment, Brahe could also enjoy the income from several personal endowments. His activities cost the crown between 1% and 2% of its total annual revenue. In return Brahe delivered to the king an annual almanac and, in addition, he constructed horoscopes, issued prescriptions, and prepared medications. The endowments came with some obligations from which Brahe tried to withdraw, but for a long time most of the resulting conflicts found a reasonable solution. However, when Christian IV took over from his father (in 1596), he wished to save expenses on research grants. Brahe misjudged the importance of his scientific reputation in comparison to the grudges that his arrogance had caused. In April of 1597, he left Hven to take up residence first in Copenhagen, then in Rostock, and finally from October 1597 at the Wandesburg Castle near Hamburg. His attempts at a reinstatement of his former privileges were in vain, as Christian IV wanted to set his own terms for his mathematician.

Early in 1598, Brahe printed a small edition of his *Astronomiae Instauratae Mechanica* with pictures and descriptions of his most important instruments, as well as a short survey of the theoretical results of his work. Moreover, his star catalog from *Progymnasmata* was extended and copied in a number of exemplars with the title *Stellarum Inerrantium Restitution*. These two publications were sent to a number of colleagues and princes. After an invitation from Emperor Rudolph II, Brahe traveled to Prague, arriving in June of 1599. Not until late in 1600 did he succeed in getting all of his instruments moved to join him. Frequent relocations and economical problems hindered a sensible work schedule. It was a disappointment to Brahe that the institution from Hven did not take root in Bohemia. However, this move became very important in the history of astronomy, because it was in Prague that Brahe gained the assistance of **Johannes Kepler**, who was to be his scientific heir.

Brahe had developed instruments of various types, including the sextant for the measurement of visual angles in random planes, quadrants for altitude measurement, and armillary spheres erected for the measurement of coordinates in relation to the ecliptic or the celestial equator. He constructed new and more accurate sights, and he equipped his measuring areas with transverse lines for more precise reading than previously available. After 10 years at Hven, Brahe was satisfied with his instruments, whose resolving accuracy had been increased to about 1′. Brahe was already dead when **Galileo Galilei** first directed telescopes toward the heavens, and yet another two generations were to pass before telescopes were equipped with the crosshairs and micrometer that could match Brahe's naked-eye instruments.

Brahe had found it necessary to take into consideration the previously unrecognized effects of atmospheric refraction. He investigated these and then constructed tables of their influence. Only one astronomical parameter, the all-too-large solar parallax of 3′, did Brahe adopt from his predecessors. This is the reason his refraction tables are not correct. Even so, in his day and age they represented progress.

Brahe observed more frequently and routinely than any other early astronomer. His results were collected and were easily accessible for later developments. Among the theoretical results was his star catalog, the first real improvement in this area since ancient times. Brahe found it necessary to work on a revision of the theories of the "wandering stars" by pinpointing more accurate positions of the "fixed" reference points. He calculated better solar tables, and his theory of the movement of the Moon included descriptions of four previously unobserved irregularities, which he partly derived using the hypothetical-deductive method. Brahe did not manage to develop complete planetary theories, but was the first one to know that the nodal line of each planetary orbit moves with its own rate of slow rotation.

Brahe observed seven comets, and wrote his main astronomical work *De Mundi Aetherei Recentioribus Phaenomenis* about the first and the largest of these. This was printed at Hven in 1588. He proved that comets move among the planets much farther away than the Moon, and thus were no more mere atmospheric phenomena than was the new supernova. This enabled him to strike a further blow against the Aristotelian cosmology, disproving the existence of hard, impenetrable planetary spheres.

In describing the structure of the Universe, Brahe had only a few dubious observations to build upon. Before 1588, he still considered the possibility of proving the view of Copernicus, and he was reluctant to bring arguments against the idea of a moving Earth. Yet, this idea appeared unreasonable to him. It conflicted with several Biblical passages, and the thought of the Universe having a wide empty space of no use between the outer planet of Saturn and the fixed stars seemed absurd. Therefore Brahe formulated his own compromise: The Sun and Moon circle around the unmoving Earth at the center of the Universe, and the five other planets circle around the Sun as a second but moveable center. Brahe had worked on this Tychonic System since 1578 and published it within his work about the comets. Oddly enough he used thereafter arguments against the Earth's movement, copied out of the Aristotelian philosophy that his own work had helped to break down. Nevertheless, Brahe could not be an orthodox believer in the Aristotelian philosophy; he preferred Pythagorean and Platonic arguments about harmony and symmetry connected with religious and astrological considerations. Connected to this train of thought, all movements in the sky should be described by circular components of motion. Brahe stuck to this principle and did not live to see Kepler's theory of elliptical planetary orbits set into the Copernican Universe.

Kristian Peder Moesgaard
Translated by: *Inger Kirsten Lutz* and *Gene M. Lutz*

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Brahmagupta

Born **Bhillamāla (Bhinmal, Rajasthan, India), 598**
Died **after 665**

Brahmagupta was an Indian (Hindu) astronomer. He probably lived at Bhillamāla (modern Bhinmal in the southwest of Rajasthan). His father was Jiṣṇu, and Brahmagupta was sometimes called Jiṣṇu-suta (son of Jiṣṇu). Brahmagupta was a follower (and possibly the founder) of the Brāhma School, one of four principal schools of classical astronomy (from late 5th to 12th centuries) active in that period.

Brahmagupta composed two principal works, namely, the *Brāhmasphuṭasiddhānta* in 628 (precise treatise of the Brāhma school), and the *Khaṇḍakhādyaka* in 665. In the *Brāhmasphuṭasiddhānta*, Brahmagupta criticized **Āryabhaṭa I**, the founder of the Ārya School. But in his *Khaṇḍakhādyaka*, Brahmagupta accepted the system of the Ārdharātrika School, another school founded by Āryabhaṭa I. Brahmagupta was a contemporary of another Indian astronomer, **Bhāskara I**, but it is not known whether they knew each other.

Brahmagupta composed the *Brāhmasphuṭasiddhānta* when he was 30 years old. He states that his work is an improved version of the astronomical system described by Brahman. If this were true, then the Brāhma School, whose name is a derivative of Brahman, might have existed before Brahmagupta. The *Brāhmasphuṭasiddhānta*, whose author and date are not definitely known, is the earliest extant work of the Brāhma School. It consists of 24 chapters (and in some editions has an added chapter of versified tables).

In classical Hindu astronomy, both geocentric epicyclic and eccentric systems are used to calculate the positions of the planets. In the *Brāhmasphuṭasiddhānta*, the method used is one of successive approximations (except for the case of Mars). This tells us that the Indian model of planetary motion was not a simple imitation of the Greek geometrical model.

Thirty-seven years later, Brahmagupta composed the *Khaṇḍakhādyaka*. In its first part, the *Pūrvakhaṇḍakhādyaka*, he followed the Ārdharātrika School, while in the second part, the *Uttarakhaṇḍakhādyaka*, he presented his own improved system. Here, Brahmagupta did not use the method of successive approximations to calculate planetary positions. He used several mathematical devices, including a second-order interpolation, for his astronomical calculations.

The Brāhma School promoted by Brahmagupta was followed by **Śrīpati** in his *Siddhāntaśekhara* and by **Bhāskara II** in his *Siddhāntaśiromaṇi*. Brahmagupta's astronomy was transmitted to Arabia in the latter half of the 8th century. Brahmagupta was well known to **al-Bīrūnī** and mentioned in his *India*.

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Brandes, Heinrich Wilhelm

Born **Groden near Cuxhaven, (Niedersachsen, Germany), 22 July 1777**
Died **Leipzig, (Germany), 17 May 1834**

Heinrich Brandes was a pioneer in the study of meteors. He was a son of Albert Georg Brandes, a Protestant minister. Following grammar-school education, he studied science and mathematics at Göttingen with A. G. Kaestner and G. C. Lichtenberg. After 10 years of work as a dike official, Brandes was appointed in 1811 professor of mathematics at Breslau University . In 1826, he succeeded L. W. Gilbert in the chair of physics at Leipzig. Brandes was married, and his son, Carl Wilhelm Theodor, was a lecturer at Leipzig.

In 1798, Brandes and his fellow student **Johann Benzenberg** performed a series of observations to determine the altitude (and velocity) of meteors by triangulation. This work, locating these objects in the upper atmosphere rather than the troposphere, eventually led to the discovery of their interplanetary nature. Later, at Breslau, Brandes organized a regional network of observers with the aim of collecting data on a larger scale. He was the first to note seasonal variations of meteor frequency. Following **Denison Olmstead**'s pioneering investigations of the Leonids, Brandes recognized the Perseids as still another periodic meteor stream.

Brandes' special ability in the field of mathematical physics resulted in a wide range of contributions to contemporary science. Beside the mathematical method developed for reduction of the meteor observations (later improved on by **Heinrich Olbers**), his contributions to the theory of cometary tails, atmospheric refraction, atmospheric physics in general, and several aspects of contemporary mechanics deserve special mention. Beside numerous technical and popular publications, Brandes' work as a coeditor of the monumental *Gehler's Physikalisches Woerterbuch* – with a large score of contributions of his own on astronomical as well as other topics – was of special value in his time.

Wolfgang Kokott

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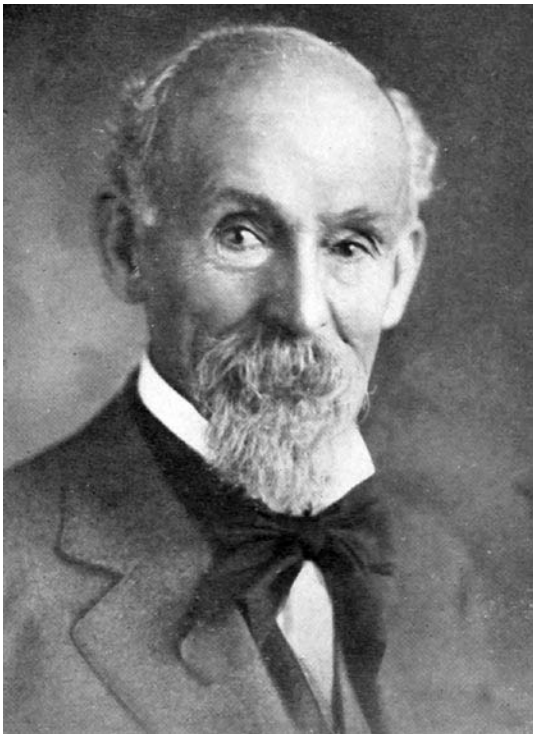
Brashear, John Alfred

Born **Brownsville, Pennsylvania, USA, 24 November 1840**
Died **Pittsburgh, Pennsylvania, USA, 8 April 1920**

John Brashear, a mechanical genius, manufactured many customized astronomical instruments for the scientific community as well as supplying substantial numbers of excellent smaller telescopes to the commercial market. Many of these smaller instruments, as well as the larger observatory grade instruments, are still in use. Brashear invented an improved and widely applied process for silvering mirrors which carries his name. He also acted as a civic leader and representative of astronomy. His support was crucial to the development of the Allegheny Observatory.

Brashear was the son of a skilled saddle maker, Basil Brown Brashear, and a schoolteacher, Julia (*née* Smith). When John was 9 years old, his grandfather took him to look through the telescope of a friend, Squire Wampler. Brashear's first look at the Moon and the rings of Saturn was through a lens made by Wampler. The flint element of the lens was crafted from glass that Wampler found among the debris of glassworks destroyed in 1845 by the great Pittsburgh fire. Brashear was so impressed by those sights that the study of the stars became his primary interest. However, as both his education and his means were meager, so also were his opportunities for employment or further education limited. When the Civil War broke out, Brashear's father enlisted in the Union Army, so Brashear went to work in the steel mills of Pittsburgh's South Side to help support his family. He earned only $10 per week, but Brashear learned well and became one of the most skilled millwrights in the city.



In 1862, Brashear married Phoebe Stewart. After his career at the mill and his marriage had stabilized, he decided to pursue his nascent interest in astronomy. He did so at first with a small and inexpensive refracting telescope mounted on a wooden tripod, but this soon proved inadequate and Brashear undertook to construct his own telescope. His initial efforts at building a telescope, though time consuming and sometimes disappointing, eventually changed his life. In 1872, in a workshop behind his home and with the assistance of Phoebe, Brashear started grinding and polishing a lens for a telescope, even though he had never read a book on astronomy or physics. After 2 years, the 5-in. lens was finished. Brashear held it to the light; it slipped and broke into two pieces, a major disappointment to Brashear and his wife. An English friend, who was visiting at the time of the accident, replaced the glass, since the Brashears had no money to buy one. However, it took 2 months for the replacement glass to be shipped from England. The telescope was completed after 3 more years of work. Soon people from the South Side neighborhood were looking through Brashear's new telescope.

Brashear showed his telescope lens to **Samuel Langley**, director of the Allegheny Observatory in nearby Allegheny City, now the north side of Pittsburgh. Impressed with Brashear's work, Langley suggested that Brashear try building a reflecting telescope.

Brashear obtained directions on mirror making from **Henry Draper**, and a procedure for silvering the mirror from a British scientific magazine, *The English Mechanic and World of Science*. However, a year later, the nearly finished mirror shattered as he attempted to silver it. This second disappointment was devastating. At Phoebe's urging, however, Brashear started another mirror and succeeded by devising his own method for silvering the mirror. He was now at a crossroad. From one advertisement in an 1879 issue of *Scientific American*, "Silvered-glass specula, diagonals and eye-pieces made for amateurs desiring to construct their own telescopes," Brashear received hundreds of orders. In response and in a manner that became typical of Brashear, in 1880 he sent detailed descriptions, formulae, and drawings of his work to *The English Mechanic*. His silvering method, later known as Brashear's process, quickly became the preferred method of silvering mirrors.

After suffering a nervous breakdown in early 1881 from hard work in the mill, along with the many hours spent working in his optical shop, Brashear considered leaving the secure living as a millwright, to become a full-time optical worker. In July 1881, Brashear received an important commission from Langley to silver a heliostat mirror for an expedition to further study the selective absorption of the Earth's atmosphere from the summit of Mount Whitney, California. He still had a mortgage on his home and a family to support. The wealthy Pittsburgh philanthropist William Thaw, Langley's long-time benefactor, came to Brashear's assistance. In addition to financing the enlargement and better equipping of Brashear's workshop, Thaw paid off Brashear's mortgage. In 1886, Thaw provided Brashear with an even larger and better-equipped workshop, and a larger home, both near the Allegheny Observatory – all at no lease cost. This unique lease arrangement was continued by Thaw's heirs until Brashear's death, and provided Brashear a release for full-time employment in optics.

After Thaw placed Brashear on a firm financial footing in 1881, Brashear made lenses and mirrors for telescopes and spectroscopes, both large and small, for people and organizations throughout the world. Scientists from all over sought his expertise in solving problems. Where adequate equipment did not exist, Brashear designed the equipment needed and instructed the buyer on using it. When Brashear constructed the Greenwich Observatory's spectroscope, for example, it was so advanced that no one at the observatory could assemble it. Through a lengthy correspondence, Brashear explained the assembly and its alignment to the observatory staff.

Brashear produced telescopic and spectroscopic optics, and other scientific apparatus, of previously unsurpassed precision. At a time when scientific research was at its technical limits, Brashear optics and equipment greatly extended that reach. Among the major achievements of the firm are 18 or more refracting telescopes with apertures from 12 in. to 30 in., four reflecting telescopes with apertures in the range of 30 in. to 72 in., and numerous spectroscopes and spectrographs for large telescope installations. The most noteworthy of the latter instruments was the Mills spectrograph designed by **William Campbell** for stellar radial-velocity measurements at the Lick Observatory. Brashear was also responsible for the manufacture of numerous optical flats, and for mirrors later ruled to produce concave gratings for spectrographs. Highly specialized optical systems were produced for the International Bureau in Paris for standardizing the length of a meter in terms of the wavelength of light, and for **Albert Michelson**'s first large interferometer.

Brashear also produced much of Langley's experimental aerodynamics equipment beginning in March 1887. He keenly felt Langley's disappointment in 1903 when his experimental man-carrying airplane failed, just months before the success of the Wright Brothers.

By 1898, when **James Keeler** left the Allegheny Observatory to direct the Lick Observatory, Brashear had become a much-respected public figure in Pittsburgh. He served as acting director of the Allegheny Observatory from 1898 to 1900, and from 1901 to 1904 he served as acting chancellor of the Western University of Pennsylvania, now the University of Pittsburgh. In both cases, Brashear refused a permanent appointment. His acceptance of these senior positions, even on a temporary basis, was made possible by the employment of James McDowell, his son-in-law who was a very capable manager of the firm in Brashear's absence.

While continuing to provide precision optics and instruments to the scientific community, Brashear also raised funds for relocating the Allegheny Observatory building beyond the smog and development of industrial Pittsburgh. Consistent with his dream of bringing the heavens to the common man, Brashear insisted that the new Allegheny Observatory include a public lecture hall and public use of the original 13-in. Fitz-Clark refractor telescope.

Popularly known as Uncle John in Pittsburgh, because of his many educational and philanthropic efforts, Brashear was appointed a trustee of the Carnegie Institute (Museums of Natural History and of Art and The Music Hall) in Pittsburgh, and to the committee that designed the Carnegie Technical Schools (now the Carnegie Mellon University.) He was actively involved in various other philanthropic efforts. As a result of his philanthropy and civic dedication, as well as his scientific enterprise, Brashear received a number of honorary degrees.

Glenn A. Walsh

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Bredikhin, Fyodor Aleksandrovich

Born **Nikolaev, (Ukraine), 26 November/8 December 1831**
Died **Saint Petersburg, Russia, 1/14 May 1904**

Comets, and especially the nature of their tails, were Fyodor Bredikhin's major preoccupation throughout his entire scientific career.

After graduation in 1855 from Moscow University, Bredikhin conducted his postgraduate study there, also working at the Moscow

Observatory. In 1862 he defended his master's thesis, *On the Tails of Comets*, and in 1864 his doctoral dissertation, *Perturbations of Comets that do not Depend on the Gravitational Attraction of Planets*. The same year Bredikhin was appointed professor at Moscow University and in 1873 became director of the university's observatory. He then succeeded **Otto Wilhelm Struve,** the first director of the Pulkovo Observatory, in 1890. Bredikhin retired from his observatory post in 1895, for health reasons.

Bredikhin held memberships in the Russian Astronomical Society, Deutsche Akademie der Naturforscher Leopoldina in Halle (1883), the Royal Astronomical Society (1884), the Italian Society of Spectroscopists (1889), and the Bureau des longitudes in Paris (1894). In 1892, the University of Padua awarded him an honorary doctorate.

Beginning with his first paper on the subject, "Quelques mots sur les queues des comètes" (1861), Bredikhin carried out extensive observational and theoretical studies of comets. His work on the subject continued after his retirement and culminated in the so called mechanical theory aimed at explaining the peculiar shape of cometary tails. They are typically directed toward the Sun near the nucleus but then curve away from it, forming multiple jets, as if they were repelled by the Sun. Bredikhin classified cometary tails into three types depending on the magnitude of this effective repulsive force. Although his theory was later abandoned, some aspects of his classification are still valid.

Bredikhin's other projects ranged from gravimetry to astrophysical spectroscopy to observations of meteor showers and the zodiacal light. His studies of the solar corona resulted in a theory that noted a connection between coronal streamers and chromospheric filaments and the lack of a direct connection between such streamers and sunspots.

Yuri V. Balashov

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Bredon, Simon

Born **England, *circa* 1310**
Died **England, 1372**

Simon Bredon observed planetary motions to investigate precession.

Bredon was a fellow of Merton College, Oxford, between 1330 and 1341, where he lectured on mathematical subjects and wrote a textbook on arithmetic. He wrote *theorica planetarum* and at least began a commentary on **Ptolemy**'s *Almagest*; the first three books (of 13) are extant in manuscript. One of the few observational astronomers of the Middle Ages, Bredon recorded a Venus–Regulus appulse and a lunar occultation of Aldebaran in 1347. The purpose of these observations was to determine the amount of precession that had occurred between Ptolemy's time and the 14th century. Bredon had a keen interest in astrology; comparing Latin translations of Ptolemy's *Quadripartitum*, he produced his own version of this text. He also aided his Merton College colleague John Ashenden in the composition of an astrological *Summa*.

Bredon's later career was that of a physician to high nobility: Joanna Queen of Scotland, Richard Earl of Arundel, and Elizabeth Lady Clare were among his patients. He may well have been the exemplar for **Geoffrey Chaucer**'s "doctour of phisik." Upon his death, Bredon left 23 scientific books and an astrolabe to Merton College.

Keith Snedegar

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Bremiker, Carl

Born **Hagen near, Hanover, (Germany), 23 February 1804**
Died **Berlin, Germany, 26 March 1877**

Carl Bremiker published convenient mathematical tables arranged to simplify and speed astronomical calculations, and edited several journals over an extended period.

Bremiker, the son of a manufacturer, Johann Carl Bremiker, was educated as a surveyor. Employed by the Rhinish–Westphalian survey immediately after he completed his training, Bremiker went to Berlin in 1835 to pursue mathematical and astronomical studies at the university. His calculation of an expected reappearance of Encke's comet (2P/Encke) was so accurate that **Johann Encke** himself commented that Bremiker's work could not have been improved upon. As a mathematician and astronomer at the Berlin Observatory, Bremiker helped prepare the *Berliner astronomische Jahrbuch*.

Between 1839 and 1858, Bremiker was intimately involved with the observation and calculation of five hours – 6, 9, 13, 17 and 21 – for the *Berliner academischen Sternkarten*, a valuable catalog and atlas created as a cooperative effort by several observatories. His completed, but as yet unapproved, chart for hour 21 was used by **Johann Galle** for his discovery of the planet Neptune near the position predicted by **Urbain Le Verrier** in 1846. In his announcement letter to Le Verrier, Galle described Bremiker's chart as excellent for this purpose.

From 1850 to 1877, Bremiker served as editor of the *Nautische Jahrbuch*. He was appointed a departmental director at the Royal Prussian Geodetical Institute in 1868.

Perhaps the greatest service to astronomy Bremiker performed was his efforts to simplify and improve the logarithm tables of Baron Georg von Vega. Bremiker's seven-place *Logarithmisch-trigonometriche Handbuch* (1856) was arranged more conveniently for complex astronomical calculations and went through 40 editions before the advent of mechanical calculators.

As a practical astronomer, Bremiker observed from his own residence with a small telescope, discovering a comet, C/1840 U1, on 26 October 1840. In 1842, Bremiker married a tailor's daughter, Ida Alwine Steuber; they had one son.

Thomas R. Williams

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Brenner, Leo

Born **Trieste, (Italy), 1855**
Died **possibly Berlin, Germany, 1928**

"Leo Brenner" was the pseudonym adopted by Spiridion Gopčević, a Serbian journalist, novelist, playwright, dabbler in the tumultuous politics of the Balkans, and one of the strangest characters ever to appear on the astronomical scene. He wrote several influential books and a host of articles that championed a variety of conflicting causes, including Serbian nationalism, Albanian independence, and a defense of the Hapsburg Monarchy. Gopčević's frequent changes of political allegiance reflect his volatile temperament and a proclivity to alienate his associates.

After marrying into wealth, Gopčević assumed the name Leo Brenner and took up astronomy at the age of 35. In 1894, he established the "Manora Observatory" on the Dalmatian island of Lošinj, located in the northern Adriatic Sea off the coast of present-day Croatia. Lošinj was then an outpost of the Hapsburg's Austro–Hungarian Empire. Equipped with a fine 7-in. refractor and aided by excellent seeing that resulted from the modest diurnal temperature variation characteristic of the island's delightful climate, Brenner issued a torrent of observational reports and quickly gained a measure of respect among lunar and planetary specialists, notably **Philipp Fauth** and **Percival Lowell**, who both visited Lošinj during the late 1890s.

The reception of Brenner's 1897 monograph describing his observations of Jupiter was typical of that enjoyed by his early work. The review in the British journal *The Observatory* was especially generous in its praise: "A really magnificent memoir… The feature which entitles the work to be called 'magnificent' consists of a series of very finely tinted charts. Concerning these it is safe to say that nothing equal to them in point of finish and quality of details has hitherto appeared." Brenner's popular books on observational astronomy, *Spaziergaenge durch das Himmelszelt* (1898) and *Beobachtungs-Objecte fuer Amateur-Astronomen* (1902), were also well received.

However, Brenner's success was destined to be short lived. According to the Austrian historian Martin Stangl, Brenner was driven by "a nearly pathological craving for fame and recognition" combined with an "overestimation of the possible." Brenner's renderings of Mars featured a canal network even more intricate than Lowell's. He also imagined that he could glimpse oceans through transient clearings in the cloud canopy of Venus and proclaimed the discovery of a laughably precise but wildly inaccurate axial rotation period of 23 h 57 min 36.27728 s, rather like a geologist estimating the age of the Earth to the nearest minute. Spurious rotation periods for Mercury and Uranus soon followed, as well as a claim that he had resolved the M31 nebula (the Andromeda galaxy) into stars, a feat well beyond the grasp of his modest instrument. Stangl does note, however, that modern planetary observations have, in certain respects, shown features that are remarkably similar to some of Brenner's observations that were criticized severely in his time.

When his observations were greeted with skepticism, Brenner retaliated by making scurrilous *ad hominem* attacks on his critics. Several influential figures became targets, notably the popular French astronomer **Camille Flammarion** and his highly respected assistant **Eugène Antoniadi**. Brenner even fell out with Lowell, and habitually heaped sarcasm and abuse on the staff and equipment of the Vienna Observatory. His reputation was all but destroyed as a result of this conduct, and he was soon regarded as a pariah by the astronomical establishment.

As Brenner's claims grew ever more incredible, many even began to suspect that his observations were outright forgeries. In 1898, the editor of the *Astronomische Nachrichten*, **Heinrich Kreutz**, refused to accept any more of Brenner's submissions. Brenner coped with this rebuff by establishing his own monthly journal, *Astronomische Rundschau*, which served as a vehicle for self-promotion and allowed him to conduct personal vendettas against the growing ranks of astronomers who dared to disagree with him. It occasionally featured counterfeit endorsements of Brenner's work by various luminaries. Many of the articles in the *Astronomische Rundschau* written by well-known figures like **Simon Newcomb**, **Thomas See**, and **Edward Barnard** were simply pirated from other journals.

In 1909, Brenner abruptly revealed his true identity to the readers of the *Astronomische Rundschau* and announced that he would cease to publish the journal, sell his observatory and library, and abandon astronomy. His fate in the years that followed is mysterious. Philipp Fauth, who remained fond of Brenner, recorded in his letters that Brenner had committed suicide, though the year and circumstances of his death are disputed to this day.

Thomas A. Dobbins and *William Sheehan*

Alternate name

Gopčević, Spiridion

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Brinkley, John

Born **Woodbridge, Suffolk, England, January 1767**
Died **Dublin, Ireland, 14 September 1835**

John Brinkley was an observational astronomer, mathematician, and director of the Dunsink Observatory. The illegitimate son of Sarah Brinkley, a butcher's daughter from Woodbridge in Suffolk, he attended a school in Benhall before going to Caius College, Cambridge. There he graduated as senior wrangler in 1788 and was the first Smith Prize winner in 1788. Brinkley was a fellow of Caius College (1788–1792) and was awarded an M.A. from Cambridge in 1791 and a D.D. from Dublin in 1806. He took holy orders while a fellow at Cambridge.

Brinkley had to work his way through university. One of his summer vacation jobs was as an assistant at the Royal Observatory, Greenwich, while **Nevil Maskelyne** was Astronomer Royal. Brinkley stayed at the observatory from 23 June to 9 November 1787, and again from 27 January to 28 March 1788, before returning to Cambridge to complete his studies. In 1790, Maskelyne recommended him for the post of professor of astronomy at Dublin. Two years later, Brinkley was appointed Andrews Professor of Astronomy and director of Dunsink Observatory. Later that year he was given the title Astronomer Royal for Ireland. He was elected fellow of the Royal Society in 1803, was president of the Royal Irish Academy (1822–1835), and was president of the Royal Astronomical Society (1825–1827 and 1831–1833). In 1826 he was appointed Bishop of Cloyne.

When Brinkley arrived in 1792, Dunsink Observatory contained only a transit instrument and was awaiting the arrival of an 8-ft. altitude-and-azimuth circle that had been ordered from Ramsden but which did not arrive until 1808. In the meantime, Brinkley made many contributions to mathematics, publishing in the *Transactions of the Royal Irish Academy* and the *Philosophical Transactions of the Royal Society of London*.

In 1808, Brinkley began to become more interested in practical astronomy and by 1810 reported the discovery of an annual parallax for α Lyrae of 2.52″, which he followed in 1814 by announcing similar results for other stars. Brinkley's results were disputed by **John Pond**, Maskelyne's successor as Astronomer Royal. But while their disagreement on the issue went on for some years, it was always conducted with moderation and politeness. Brinkley was awarded the Copley Medal by the Royal Society for his work on stellar parallax, but he ultimately was proved wrong, and the incident brought about recognition for the need for a closer scrutiny of instrumental defects.

In 1814, Brinkley published a new theory of astronomical refraction, along with tables for its calculation, and published a catalog of 47 fundamental stars. He also made contributions to the determination of the obliquity of the ecliptic, the precession of equinoxes, and the constants of aberration and lunar nutation. His textbook, *Elements of Astronomy*, was first published in 1813 and went through numerous editions to become a standard reference work.

Mary Croarken

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Brisbane, Thomas Makdougall

Born **Brisbane House, (Strathclyde), Scotland, 23 July 1773**
Died **Brisbane House, (Strathclyde), Scotland, 27 January 1860**

Thomas Brisbane's contribution to science was primarily as a patron. Brisbane established three private observatories, at Brisbane House in Scotland (1808), at Parramatta near Sydney, Australia (1822), and at Makerstoun in Scotland (1826). As a Southern Hemisphere observatory, the modest establishment at Parramatta made a valuable contribution to mapping the southern skies. In addition to astronomical work at Makerstoun, a program of magnetic observations begun in 1841 was of lasting scientific value.

The eldest son of Thomas Brisbane and Eleanor (*née* Bruce), Brisbane was educated by tutors at home, at an academy at Kensington, and at Edinburgh University. His military career began in 1789 as an ensign in the 38th regiment in Ireland. Brisbane was promoted several times in successive years and saw action in Flanders under the Duke of York. He went to the West Indies in 1795 as major in the 53rd regiment. Although Brisbane developed a taste for mathematics and astronomy at the University of Edinburgh, it was an incident in 1795 that triggered his lifelong engagement with practical astronomy. The ship on which he was traveling to the West Indies was very nearly wrecked due to a miscalculation of longitude. Brisbane acquired his first instruments and soon taught himself nautical astronomy. The tropical conditions in the West Indies wore down Brisbane's health, and he returned home in 1803 as a lieutenant colonel. When he was unable to join the 69th regiment in India in 1805, Brisbane went on half pay for some years.

While in semiretirement from the army in 1808, Brisbane built an observatory at Brisbane House, borrowing against his future inheritance to equip it with fine instruments. His efforts and investment made the Brisbane House Observatory much superior to the only other Scottish observatory, at Garnet Hill, the Royal Observatory in Edinburgh not being founded until 1818.

Brisbane returned to active service in 1812, seeing action in Spain and the south of France during the Peninsular War. The following year he went to Canada as a major general and assumed command of Peninsular veterans at the battle of Plattsburg, New York. Following the battle of Waterloo in 1815, Brisbane was part of the army of occupation in France.

In 1819, Brisbane married Anna Maria Makdougall, heiress of Sir Henry Hay Makdougall. Under the terms of the marriage settlement, Brisbane adopted the middle name Makdougall in 1826. Their four children predeceased them both.

After some years largely spent in Scotland, Brisbane returned to public life in a civil position. Aware that Southern Hemisphere astronomy offered great opportunities for scientific discovery by building on the work of **Edmond Halley** and **Nicholas de La Caille**, Brisbane sought an appointment as Governor of New South Wales and made plans for his second observatory. With news of his appointment in 1821 he purchased instruments by Troughton and Reichenbach to equip an observatory and employed the established astronomer **Karl Rümker** as assistant and the mechanically minded fellow Scot James Dunlop as second assistant.

At the time Brisbane built the observatory at Parramatta in 1822, plans for an official British observatory had settled on Cape Town. However, it was some years before the South African observatory was fully operational. Therefore, Brisbane's private establishment was able to contribute novel observations to European scientific periodicals. Brisbane himself observed the solstices in 1823 as well as an inferior conjunction of Venus. More significant was Dunlop's rediscovery of Encke's comet (2P/Encke) on 2 June 1822, based on Rümker's calculations. This was only the second time that the return of a comet had been predicted and observed, Halley's comet (IP/ Halley) being the first in December 1758. In 1823 Rümker left Parramatta, but the less-experienced Dunlop remained as the principal observer. Brisbane was an active participant in the work of the observatory for the first year, but then the demands of his official duties forced him to leave the astronomical work substantially to Rümker and Dunlop.

Brisbane held the post as Governor of New South Wales for 4 years. During that period, his administration is credited with a number of reforms that were important to the rapid evolution of the new colony, including more effective applications of convict labor, enhanced surveying and sale of government lands, inauguration of free immigration on a large scale, and the encouragement of new crops. During those 4 years, the area of cleared land was doubled, and the export of wool quintupled. In spite of these successes, however, Brisbane's administration was staffed with contentious individuals appointed by the Crown, and their reports to London carried considerable negative weight. In consequence, and in spite of substantial progress being made in the colony, Brisbane was not favorably regarded in London and was recalled in December 1825.

Brisbane turned over the records for the stellar observations made at Parramatta between 1822 and 1826 to William Richardson at the Greenwich Observatory in 1830. The objective of Brisbane's observing program had been to compile a catalog of all stars brighter than the eighth magnitude from the zenith at Parramatta to the South Celestial Pole. From these observations, Richardson compiled the *Parramatta Catalogue of 7385 stars for the equinox of 1825*.

On his retirement to Scotland, Brisbane took up residence at Makerstoun near Kelso on the Tweed River. There he established his third astronomical observatory, where he took an active part in the observations himself for some 20 years. The particular importance of the Makerstoun Observatory rests on its role as a magnetic observatory under the direction of John Allen Broun. After 1841, the observatory took part in the international program established by **Carl Gauss**. Despite the effect of active military service on his health and the anxieties of colonial administration, Brisbane lived for nearly 35 years after his retirement, dying at the age of 87.

Brisbane was elected a fellow of the Royal Societies of London (1810) and Edinburgh (1811). In 1833 he succeeded Sir Walter Scott as president of the latter, an office he held until his death. An early member of the Astronomical Society of London, later the Royal Astronomical Society [RAS], he was one of its vice presidents in 1827. The RAS awarded Brisbane its Gold Medal in 1828 for his contribution to Southern Hemisphere astronomy. Brisbane was knighted [KCB] with other Peninsula War generals in 1814, and was awarded honorary degrees by the universities of Edinburgh (1823), Oxford (1832), and Cambridge (1833). Broader public recognition came with the award of a baronetcy (1836) and the GCB (1837). The Edinburgh Royal Society awarded him its Keith Medal in 1848 in recognition of the valuable work of the magnetic observatory.

Julian Holland

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Brooks, William Robert

Born **Maidstone, Kent, England, 11 June 1844**
Died **Geneva, New York, USA, 3 May 1921**

An American astronomer known for his work as a discoverer of comets, William Brooks was the son of a Baptist minister, Reverend William Brooks, and Caroline (*née* Wickings) Brooks. When still a small boy William accompanied his family on a voyage to Australia, during which his interest in astronomy was piqued by watching the ship's captain make latitude and longitude determinations. At the age of 13 he immigrated with his family to Marion, New York, USA The bright and graceful comet C/1858 L1 (Donati) of 1858, which he viewed through a homemade spyglass, fascinated Brooks shortly thereafter but did not lead to his active involvement in astronomy at that time.

After his marriage to Mary E. Smith of Edwardsburg, Michigan, in 1870, Brooks settled at Phelps, in the Finger Lakes district of upstate New York, where he worked as a photographer. In his spare time, Brooks built the Red House Observatory (actually no more than a small observing platform built in an apple orchard on his property), and from that vantage point searched for comets with several portable telescopes, including a homebuilt 5-in. reflector. He found his first comet in 1881 (72P/1881 T1), though a delay in the announcement led to the comet's becoming generally known as Denning's comet. (It was then lost until a rediscovery by S. Fujikawa in 1978.) Brooks's next comet was discovered in 1883 (C/1883 D1); he found no less than three in the single year 1886.

In 1888, Brooks was invited to Geneva, New York, to take charge of an observatory built by William Smith, a wealthy nurseryman who also emigrated from England. Built on the site of Smith's mansion, the observatory consisted of a two-story tower with a dome, designed by Warner and Swasey, housing a superb short-focus 10.5-in. Clacey refractor. In addition to receiving the keys to the observatory, Brooks and his family were quartered comfortably in a large Victorian brick house on the premises. In addition to his role as director of the observatory, Brooks served as a professor of astronomy at Hobart College from 1900, and at William Smith College as well.

Brooks remained single-minded in the pursuit of comets, and became the most prolific visual discoverer of comets in America, second on the all-time list only to **Jean Pons** of the Marseilles Observatory. To the 11 comets he had found at Phelps, he added 15 more at Geneva between 1888 and 1905. The record is the more remarkable in that he had to carry out his comet seeking, as he wrote:

> in the few intervals between other duties, among which is the entertainment of visitors, the Observatory being freely open to the public on every clear night. This explains why most of my Geneva comets have been discovered in the morning sky.

Brooks discovered his last comet, C/1911 O1, in July 1911. It turned out to be his best. Brightening rapidly as it approached the Sun and the Earth, by mid-October it loomed in the northeastern sky after evening twilight, reaching second magnitude with a bluish-white tail extending 30° and putting on a display little inferior to that put on by Halley's comet a year earlier.

Over his lifetime, Brooks independently discovered 31 comets, 21 of which bear his name in the historical records. For his comet discoveries in 1883, 1885, 1886, and 1887, Brooks was awarded the Warner Prize eight times. (**Lewis Swift** designated the recipients of the Warner Cash Prize for new comet discoveries, acting as a proxy for H. H. Warner, a patent-medicine vendor and astronomical patron at Rochester, New York.)

A few years before his death, Smith willed his mansion, observatory, and the observatory director's Victorian residence to Hobart College (later Hobart and William Smith Colleges). After Brooks's death, his daughter bought the "director's house" from Hobart. She lived there until 1954, but the observatory fell into neglect; its astronomical work had ended with the career of the director.

William Sheehan

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Brorsen, Theodor Johann Christian Ambders

Born **Nordborg, Denmark, 29 July 1819**
Died **Nordborg, Denmark, 31 March 1895**

Theodor Brorsen is best known for his discovery of five comets; he also dedicated himself to observation of the zodiacal light and the counterglow or gegenschein. Brorsen was the son of ship captain Christian August Brorsen and his wife Annette Margrethe Gerhardine (*née* Schumacher), a granddaughter of a local official. At the age of seven, Brorsen entered a Protestant school in Christiansfeld. His secondary education was obtained at the Latin school in Flensburg.

Originally a student of law, he visited the Berlin Observatory (then directed by **Johann Encke**) and enrolled in some astronomy and mathematics courses. Brorsen's studies were continued at the universities of Kiel and Heidelberg.

While a student, Brorsen discovered two comets with a small telescope at the Kiel Observatory, on 26 February and 30 April 1846 (5D/1846 D2 and C/1846 J1). His third comet, 23P/1847 O1 (Brorsen–Metcalf), was discovered on 20 July 1847 at the Altona Observatory near Hamburg, where he was appointed after completing his studies. Founded by Danish King Frederik VI in 1816, that observatory became fully operational in 1821 and was directed by **Heinrich Schumacher**, the founding editor of the journal, *Astronomische Nachrichten*.

Soon, Brorsen received other invitations. He declined a position as observer at Rundetaarn Observatory in Copenhagen, but accepted an invitation from English banker and Hamburg shipowner John Parish in 1847 to work at his private observatory at Senftenberg Castle in northeastern Bohemia. Parish's observatory had been founded in 1844. Brorsen and Parish began to rebuild the observatory with Schumacher's advice. The new observatory consisted of a meridian room and a dome housing an equatorially mounted refracting telescope. It became the best-equipped observatory in Bohemia, being larger than the main Prague Observatory at Clementinum College. During his stay in Bohemia, Brorsen became a member of the "Lotos," a German association of natural scientists founded in Prague. Both Brorsen and Parish maintained an active scientific correspondence with astronomers in Germany and elsewhere.

About 40 of Brorsen's observational and theoretical papers were published in the *Astronomische Nachrichten*. They were concerned mainly with comets, the zodiacal light, and the positions of minor planets. Brorsen had only a single, healthy eye; the other was damaged while playing with a sword during his youth. He liked to observe faint, diffuse objects; he discovered five comets and two galactic nebulae. While in Senftenberg, he regularly observed the zodiacal light and was the first to study thoroughly the spot of light termed the gegenschein. Brorsen believed that the latter was a "cometary tail" of the Earth, directed away from the Sun.

After John Parish's death in 1858, the heir, Georg Parish, returned from the United States. He introduced severe economic measures for the entire Senftenberg properties, and the observatory was declared a frivolity. Brorsen would have liked to continue his observations, even without receiving a salary, but the new owner had no understanding of science. The observatory was dismantled and the instruments were sold to observatories at Vienna, Madrid, and Tübingen. Unemployed, Brorsen moved to a small house and lived with his Czech housekeeper in Senftenberg; he never married. During those years, he devoted himself to other scientific interests, including geology, mineralogy, paleontology, and botany. In 1870, Brorsen returned to Als and never resumed astronomical observations.

Brorsen was awarded a Gold Medal by Christian VIII, King of Denmark, in 1846. This medal is displayed in the Brorsen exhibition at the Museum in Sonderborg (Als). Minor planet (3979) bears his name.

Martin Solc

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Brouwer, Dirk

Born **Rotterdam, the Netherlands, 1 September 1902**
Died **New Haven, Connecticut, USA, 31 January 1966**

Dutch–American Dirk Brouwer made significant contributions to the field of celestial mechanics (understanding the orbits of natural and artificial bodies) and pioneered the use of digital computers to solve problems with unprecedented accuracy. The son of Martinus and Louisa (*Née* Van Wamelen) Brouwer, Dirk graduated from high school in Rotterdam and attended the University of Leiden, studying mathematics and astronomy. He received his doctorate in 1927 under the guidance of **Willem de Sitter**, while serving as an assistant at the Leiden Observatory. Thereupon, he received a one-year fellowship from the International Education Board to study at the University of California at Berkeley and Yale University. Brouwer remained at Yale for the rest of his life, starting as a research assistant to **Ernest Brown** in 1928, being named an assistant professor in 1933, and in 1941 becoming a full professor, chairman of the Department of Astronomy, editor of the *Astronomical Journal*, and director of the Yale Observatory. In 1944, Brouwer was named Munson Professor of Natural Philosophy and Astronomy, in 1951 became a fellow of the National Academy of Sciences, and in 1955 received the Gold Medal of the Royal Astronomical Society. In 1966, he received the Bruce Medal of the Astronomical Society of the Pacific. Brouwer superintended the transfer of the Yale Southern Station from South Africa to Australia, occasionally working at both sites. His best-known Ph.D. students are Raynor Duncombe (who moved into aerospace engineering) and William Klepzinsky, and Yale produced a number of other outstanding students and young researchers in celestial mechanics during his tenure there.

Brouwer's work on celestial mechanics (or dynamical astronomy, as it was then known) began with his work at Leiden, where he published papers on the orbits of the satellites of Jupiter and the mass of Titan. He next collaborated with Brown at Yale to determine variations in the Moon's orbit caused by random variations in the Earth's rotation rate. Brouwer determined that these fluctuations were from disturbances in the interior of the Earth and coined the phrase "ephemeris time" for a time independent of those fluctuations. On realizing that some errors in the predicted and observed positions of the Moon were due to incorrectly located reference stars, not errors in his theory, Brouwer studied asteroids to provide an independent astronomical measuring stick. This led to the study of the origin of asteroids, and he made contributions to the understanding of the Hirayama families of asteroids and the existence of the Kirkwood gaps in the asteroid belt.

In collaboration with **Wallace Eckert** at International Business Machines and **Gerald Clemence**, Director of the Nautical Almanac Office of the US Naval Observatory, Brouwer pioneered the application of computers to solve orbital problems and to efficiently compile star charts from raw data. The most impressive result of this collaboration was the publication in 1951 of the coordinates of the five outer planets from 1653 to 2060, a calculation of unprecedented magnitude and accuracy, and a standard still referred to today. Brouwer and Eckert's computationally simple and efficient methods of differential corrections of orbits of planets and satellites were adopted throughout the world. Brouwer's work on methods of integrations and analysis of the accumulation of errors was also important to the field.

Celestial mechanics experienced a resurgence of interest following the launch of Sputnik in 1957. To meet the growing demand, Brouwer sponsored Summer Institutes in Dynamical Astronomy [SIDA] and in 1961 wrote the highly regarded *Methods of Celestial Mechanics* with Clemence. Brouwer also made significant advances in orbit calculations of artificial satellites, including algorithms that took into account the oblateness of the Earth and atmospheric drag effects on computing the motion of artificial satellites.

The American Astronautical Society and the Society's Division on Dynamical Astronomy each sponsor a Dirk Brouwer Award. He further has been memorialized by having a crater on the Moon and a minor planet (1746) named for him.

Brouwer's papers are housed at the Yale Observatory Archives.

Michael Fosmire

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Brown, Ernest William

Born **Hull, England, 29 November 1866**
Died **New Haven, Connecticut, USA, 22 July 1938**

Ernest Brown is chiefly remembered for his outstanding work in celestial mechanics, more specifically his meticulous researches into the complex intricacies of lunar theory. He was the only surviving son of wealthy farmers William and Emma Martin Brown; he had two sisters, and a brother who died in infancy.

Educated at East Riding College, Hull, Brown quickly showed an aptitude for mathematics, and in 1884 won a scholarship to Christ's College, Cambridge. There he studied under **George Darwin**, with whom he developed a friendship that lasted until the latter's death in 1912. Indeed it was Darwin who urged him to study **George Hill**'s papers on the theory of the Moon.

That was in the summer of 1888. Brown had by then spent a year in postgraduate study at Cambridge. The suggestion set the pattern of his scientific career. For the next 20 years little else occupied his professional mind, and though in the remaining 30 years his interests broadened to embrace independent problems – including the stellar version of the three-body problem, the numerical verification of solar perturbations in the Moon's motion, the motion of bodies near Lagrangian points, and the general theory of the Trojan group of asteroids – lunar theory by far remained his favorite subject. He rarely ventured outside the realm of celestial mechanics.

Brown received his B.A. as sixth wrangler in 1887. He became a fellow of Christ's College in 1889; that same year on 11 January he was elected a fellow of the Royal Astronomical Society. Brown obtained his M.A. in 1891. That year, he left his native shores for the United States to take up an appointment as instructor of mathematics in Haverford College; 2 years later, he became professor of mathematics. Distance however, could not diminish Brown's strong affection for his old *alma mater*, and part of almost every summer he returned to Cambridge, frequently staying at the Darwin residence, even long after Darwin's death.

Brown received his D.Sc. in 1897, and became an honorary fellow of Christ's College (1911). He was elected a fellow of the Royal Society (1897), and awarded its Royal Medal in 1914. Other honors Brown received include the Gold Medal of the Royal Astronomical Society (1907), the Pontécoulant Prize of the Paris Academy of Sciences (1910), and the Bruce Medal of the Astronomical Society of the Pacific (1920). The Watson Medal of the United States National Academy of Sciences (1937), an institution of which he was elected a member once he became an American citizen, was one of his more cherished awards, possibly because it did not specifically relate to his work on lunar theory but rather to his contributions to other aspects of celestial mechanics.

Brown did not intend to develop a completely new lunar theory when he started his investigation of the Moon's motion. Rather, it evolved as he became more familiar with the whole field and familiarized himself with the various methods available for use in its study. Systematic development began in 1895, with the results published in five parts in the *Memoirs of the Royal Astronomical Society* (1897–1908). Brown always gave Hill his full and proper share of the credit for his solution of the main problem, but though he followed Hill's example, and assumed the Sun, the Earth, and the Moon to be of spherical form, with the center of the Earth–Moon system performing an elliptical orbit around the Sun, "it would be unfair … to consider his work merely a routine application of Hill's methods" (Brouwer, "Obituary," 302). The objective was no less than a new determination of each coefficient in longitude and in latitude with greater completeness and accuracy than his predecessors had found.

Among the few lunar motions that had evaded elucidation was the comparatively large fluctuation in mean longitude. **Simon Newcomb** had attributed the discrepancy to irregularities in the rate of rotation of the Earth. If that were so, Brown argued, similar fluctuations should be present in the observed mean longitude of other bodies in the Solar System. His investigation of transits of

Mercury seemed to verify the supposition, but not enough to convince him of its reality. Brown devoted much thought to the problem; in 1926, after rejecting several possibilities, he concurred with Newcomb, attributing the apparent discrepancy to irregular variations in the Earth's rate of rotation. The construction of new tables of the Moon's motion, rendered with the incomparable assistance of Henry B. Hedrick, followed directly on completion of the theory. In 1907, Brown became professor of mathematics at the Yale University, where he was, in succession, Sterling Professor of Mathematics (1921–1931), the first Josiah Willard Gibbs Professor of Mathematics (1931/1932), and professor emeritus.

Brown reached an agreement with Yale to undertake the cost of production of his tables. *Tables of the Motion of the Moon*, printed by Cambridge University Press, appeared in three volumes from Yale University Press in 1919. They contained 660 pages of tables and text, with explanations of their use. Although they included nearly five times more terms than **Peter Hansen** had used in his tables, they were more convenient to use, and in 1923 were incorporated into most national ephemerides for the calculation of the Moon's place.

As a young man Brown was a keen mountaineer, and traveled extensively. He was an accomplished pianist, and fond of music. He read widely, but as he got older developed a taste for detective stories. Brown never married, and made his home with his unmarried sister, who sadly predeceased him by about 2 years. Long-standing bronchial troubles precipitated early retirement in 1932, and shadowed his last 6 years.

Richard Baum

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Brown, Robert Hanbury

Born **Aruvankadu, (Tamil Nadu, India), 31 August 1916**
Died **Andover, Hampshire, England, 16 January 2002**

British radio astronomer R. Hanbury Brown is best known for the invention and development, with Robert Twiss, of optical intensity interferometry. He was named after a grandfather, who worked on irrigation with the Royal Engineers in Egypt and India, where his father, also a soldier, was born and stationed at the time of the astronomer's birth. Later in his life, the surname was sometimes rendered as Hanbury Brown, and he was generally called Hanbury.

Brown was educated at Tonbridge School and took a first class degree in electrical engineering at Brighton Technical College in 1935. He went on to Imperial College, London, intending to work toward a Ph.D. Instead, Brown became involved almost immediately with the London University Air Squadron and the Air Ministry, where he was put to work on the pioneering research on radar then under way under Robert Watson-Watt. He also helped develop beacons for aircraft and ground stations to distinguish friendly from unfriendly aircraft, which were used in the allied invasion of Europe in 1944. Brown was seconded to the United States Naval Research lab (1942–1945), working on similar projects there. He continued to work with Watson-Watt as a consultant until 1949, when he joined **Bernard Lovell** at the Jodrell Bank radio observatory of University of Manchester, intending again to work toward a Ph.D. but again being diverted. Brown was appointed a senior lecturer at the university in 1953, a reader in 1955, and to a professorship of radio astronomy in 1960, from which he resigned in 1963 following a move to Australia. He married Heather Chesterton, and they had three children.

When Brown went to Manchester University's Jodrell Bank in 1949 the only radio telescope there was Lovell's handmade 66-m dish, which could only point to the zenith. Brown, along with a graduate student, Cyril Hazard, modified the telescope so that it could be moved to other altitudes on the meridian. Their results with this crude arrangement were an important practical demonstration of the need for a large, steerable radio telescope, which was eventually completed at Jodrell Bank in 1957. Working at a wavelength of 1.89 m, Brown and Hazard, in 1950, showed conclusively that M31 emitted radio waves. It was the first of many extra-galactic radio sources that they identified and mapped. The pair also confirmed the earlier work of **Grote Reber**, detecting emission from the Milky Way and from a few discrete sources, though at better resolution than had been possible earlier. At the time, it was not known if radio sources such as those in Cygnus and Cassiopeia were starlike. There had been a few successful demonstrations of stellar diameters at optical wavelengths by **Albert Michelson** and **Francis Pease** in the 1920s using an interferometer. But because radio wavelengths are much longer, a comparable radio interferometer would have had to be immense. So Brown set out to devise a different type and, together with mathematician Richard Twiss, invented a device that he called an intensity interferometer.

In all interferometers, waves from a source fall on two or more receivers the separation of which can be varied. In the traditional design, the phase relationship between these collected waves must be preserved up to the point where they are added, implying that the receivers must be physically connected and that the difference in path lengths to the point of combination must be known very accurately. In the intensity interferometer this phase preservation is not necessary since the radiation is collected at two separate receivers and transmitted by phone or radio link to an electronic device where only the fluctuation in power from each receiver is correlated. The intensity interferometer had the unexpected advantage of being unaffected by atmospheric scintillations, too. With the first intensity interferometer, built by two of Brown's research students, Roger C. Jennison and M. K. Das Gupta, the angular diameters of the radio sources Cygnus A (Cyg A) and Cassiopeia A (Cas A) were actually measured to be arc minutes in size, thus proving that they were not starlike. This result did not entirely resolve the issue of whether most sources were galaxies (expected to be extended) or associated with stars (expected to be compact). In fact Cas A is a supernova remnant and Cyg A an active galaxy. Since these sources were much larger than expected, it happened that other radio astronomers were simultaneously obtaining the same measurements using traditional interferometric techniques with only moderate antenna separation.

As it turned out, mainly due to the development of highly accurate frequency standards, the traditional amplitude interferometer, rather than the intensity interferometer, became the instrument of choice in radio astronomy. But the intensity interferometer's immunity from atmospheric scintillation convinced Brown and Twiss that if they could adapt it to optical wavelengths, it would overcome one of the major problems that had prevented Michelson and Pease from making further progress in the 1920s. Since separate detectors were used, it moreover avoided the need for extreme mechanical stability. However, many physicists were skeptical that the principle was sound, and a great deal of time and effort went into proving that it was – even when the results came in, proving that the method worked. Brown and Twiss had their first success in this connection in 1956 when they measured the angular diameter of Sirius at optical wavelengths as 7.1 milli-arcseconds, an achievement that required only 18 h of actual observing but 5 months to accumulate in the poor English climate (an important factor in Brown's move to Australia). Even more important was the willingness of the School of Physics at the University of Sydney to share with the University of Manchester in the large expense by installing and maintaining the equipment at Narrabri, a site some 500 km outside the city. As a result, Brown moved to a professorship at the University of Sydney, retiring into a fellowship in 1981, and returning with Heather to England in 1989.

Though the skies were wonderfully dark, there were huge problems in getting the intensity interferometer up and running in the remote Australian bush. There were two multiple mirror telescopes 6.5 m in diameter mounted on carriages that could be moved around a circular track 188 m in diameter. Brown's persistence paid off over the course of 7 years (1965–1972); he and his coworkers measured the angular diameters of 32 main sequence stars ranging from spectral types O through F. This information was a key in determining the stars' effective temperatures from observation, which could then be compared with theoretical studies of stellar structure and atmospheres. The interferometer was further used to investigate the binary parameters of Spica; limb darkening in Sirius; a possible corona around Rigel; emission regions surrounding the Wolf–Rayet star, γ Velorum; the effect of rotation on the shape of Altair; and finally in a search for gamma ray sources.

Brown did consider designing a larger intensity interferometer, but concluded that recent optical and electronic developments would enable the traditional type of interferometer to be modified to work more efficiently. He and his group worked in the laboratory to develop such a new instrument beginning in 1975, and the new Sydney University Stellar Interferometer [SUSI] came into service in the early 1980s.

During his years in Australia, Brown welcomed thousands of visitors to the Narrabri Observatory, but he wished to convey more adequately to the public what astronomers were doing and why. This prompted him to write *Man and the Stars* (Oxford University Press, 1978) and, after retirement *The Wisdom of Science: Its Relevance to Culture and Religion* (Cambridge University Press, 1986). *Boffin, a Personal Story of the Early Days of Radar, Radio Astronomy and Quantum Optics* (Adam Hilger, Bristol, 1991) is his own account of his career. Very appropriately, Brown received the Albert Michelson Medal of the Franklin Institute in recognition of his measurements of angular diameters of stars. He received an Eddington Medal and was foreign associate of the Royal Astronomical Society (London) and a fellow and Hughes Medalist of the Royal Society (London), as well as recipient of honors from the Australia Academy of Science and from the Australian government. Brown served as president of the International Astronomical Union from 1982 to 1985 and presided at the General Assembly held in 1985 in India (Delhi) where he was born.

Peter Broughton

Alternate name

Hanbury Brown, Robert

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Brück, Hermann Alexander

Born **Berlin, Germany, 15 August 1905**
Died **Edinburgh, Scotland, 4 March 2000**

Hermann Brück was a distinguished astronomer responsible for the resurgence of interest in astronomy in post-war Ireland and for raising the Royal Observatory Edinburgh [ROE] to an internationally recognized research center. He served as Astronomer Royal for Scotland from 1957 to his retirement in 1975.

Brück was the only child of Hermann Heinrich Brück, an officer in the Prussian army who was killed in action during the battle of Lodz in 1914, and his wife Margaret. Educated at the Kaiserin Augusta Gymnasium, Charlottenburg, famed for its teaching of Greek, Latin, and mathematics, Brück matriculated at Kiel University in 1924. After a period there and at Bonn University, he moved to Munich. He studied there under the eminent physicist Arnold Sommerfeld and in 1928 gained his doctorate, which concerned the wave mechanics of crystals. Brück fondly remembered this period, as a student of theoretical physics, throughout his career and long life. He followed his friend **Albrecht Unsöld** into the field of astronomical spectroscopy by securing a post at the Potsdam Astrophysical Observatory.

In 1935, Brück converted to Catholicism and with the threat of Nazism, fled Germany a year later, taking refuge with Jesuits in Italy along with his first wife Irma Waitzfelder (whom he married in Rome and who died in 1950). Brück's faith would remain an integral part of his persona, and he was a long-standing member and councillor of the Pontifical Academy of Sciences. For his services to the Roman Catholic Church, when Brück was 90, Pope John Paul II conferred on him the Knight Grand Cross of the Order of Saint Gregory the Great.

After a year at the Vatican Observatory, Brück came almost penniless to England in 1937 and secured a position at Cambridge. Here he worked under Sir **Arthur Eddington**, working on telecommunications though maintaining his interest in solar physics, and eventually progressing to the position of John Couch Adams Astronomer. In 1946, Brück was made assistant director of the Cambridge Observatory.

In 1947, the Irish Prime Minister, Eamon de Valera, invited Brück to become director of the Dunsink Observatory (near Dublin) and professor of astronomy at the Dublin Institute for Advanced Studies. Here Brück joined a distinguished group of scientists (among them was his friend, Nobel laureate **Erwin Schrödinger**) and began the task of revitalizing Dunsink, which had fallen into disuse since the founding of the Irish State.

The hosting of the International Astronomical Union's [IAU] triennial Assembly in Dublin in 1955 evidenced the success of Brück's initiative in reestablishing Irish astronomy. Among the exhibits were the photoelectric photometer developed by M. J. Smith, who had been Brück's student in Cambridge, and the ultraviolet solar work that formed part of the Utrecht atlas.

Another Nobel laureate, Sir **Edward Appleton**, principal of Edinburgh University, offered Brück further challenges when, in 1957, Appleton appointed him professor of astronomy and Astronomer Royal for Scotland. Here Brück was to initiate the development of innovative instruments for automated scanning of spectra, for measuring star and galaxy images, and for remote operation of telescopes, which led to the ROE operating the UK Schmidt telescope in Australia and the UK infrared telescope in Hawaii. In 1965, Brück first proposed that a large telescope be built in the Northern Hemisphere, but outside Britain. Site testing was carried out under ROE management, and the final outcome was the observatory at La Palma. These and other programs were to put the ROE at the forefront of the technological revolution embracing astronomy in the 1960s.

Brück was an excellent educator and took great enjoyment and pride from his public lectures. One of his most memorable lectures, on the life and work of **Angelo Secchi**, was the opening address at the IAU Colloquium 47 in Rome in 1978. Brück also expanded the astronomy teaching at Edinburgh and introduced a new honors degree in astrophysics starting in 1967.

Brück remained at Edinburgh until his retirement in 1975 when his attentions turned to the history of astronomy. With his second wife, Mary Conway, an astronomer herself whom he had married in 1951, Brück wrote the definitive work on the life of **Charles Smyth**, Astronomer Royal for Scotland between 1845 and 1888. Another book charted the history of astronomy in Edinburgh.

Brück was made a CBE in 1966 for his work at Edinburgh and received honorary degrees from the National University of Ireland and the University of Saint Andrews. He was a member of the Royal Irish Academy and a fellow of the Royal Society of Edinburgh.

Alastair G. Gunn

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Brudzewski, Albertus de

Born **Brudzewo, Poland, 1446**
Died **Vilnius, (Lithuania), 1497**

Albert Brudzewski lectured on planetary motions at the University of Cracow, where **Nicolaus Copernicus** may have studied with him.

Brudzewski studied in Cracow, where he received his bachelor's degree in 1470 and his master's in 1474. Soon after, he was granted a professorship at that university, a position in which he regularly gave lectures on various subjects in physics and astronomy. Subsequently, he changed to theology, obtained his baccalaureate in 1490, and went to Vilnius as secretary for Prince Alexander of Lithuania, who later became the King of Poland.

Brudzewski was a methodical, skillful, and effective lecturer. The humanist Philipp Callimachus wrote in a letter: "Everything created by the keen perceptions of Euclides and Ptolemaeus, [Brudzewski] made a part of his intellectual property. All that remained deeply hidden to lay eyes, he knew how to set before the eyes of his pupils" (Prowe, p. 144). He succeeded in molding countless young masters, who became instructors in the arts departments of Cracow's Faculty of Arts, and whose intellectual focal point was occupied by Brudzewski himself. Because of him the University of Cracow at this time enjoyed a Europe-wide reputation for excellence in the study of mathematics. This renown was also based on the fact that Brudzewski introduced what was then the best theory of planetary motion, the one formulated by **Georg Peurbach**, into the academic curriculum at Cracow. He lectured on arithmetic, Peurbach's planetary theory, **Māshā'allāh ibn Atharī**'s works, optics, several of **Aristotle**'s writings, the heavens, meteorology, *etc*.

It can be assumed that Copernicus must have entered into Brudzewski's readings as part of his studies in Cracow, especially the commentary on Aristotle. In addition to this, it is possible that Copernicus might have had personal contact with this scholar, who, in addition to his mathematical treatment of the movement of stars, also undertook observation of the heavens using such instruments as the astrolabe. However, there is no indication that Brudzewski ever derived any doubts about his geocentric world system from Copernicus' views.

Brudzewski belonged to that group of scholars who were affiliated with philosophical nominalism but who stood in the humanist camp. His duties at the University of Cracow allied him with the advocates of realism who were defending scholasticism and who had, at that time, won a temporary measure of influence.

Of Brudzewski's work, only the commentary on Peurbach's theory of the planets appeared in print. It is likely that this work, which was published in 1494 and 1495 in Milan, was originally conceived as a textbook for his lectures conducted in 1482. Numerous other works on both astronomy and astrology are held in the University of Cracow's library.

Jürgen Hamel

Alternate names

Albertus Blar de Brudzewo
Albert Brudzewski

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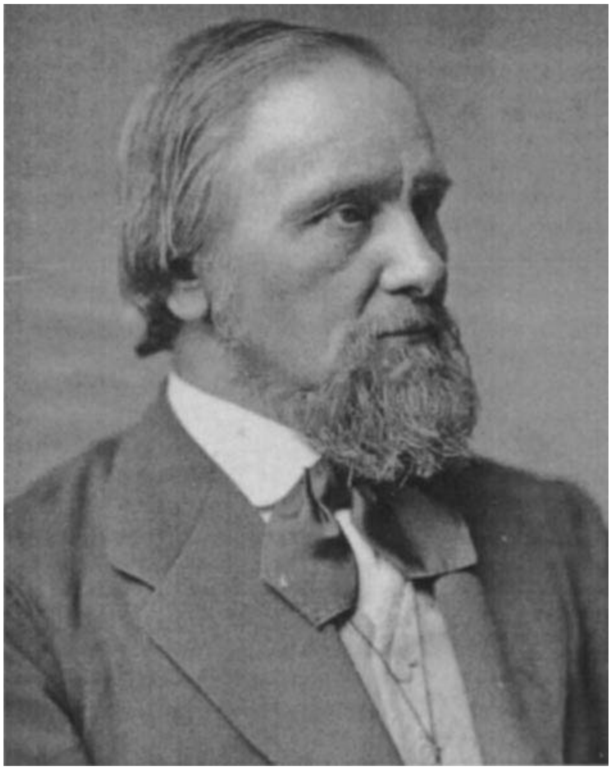
Bruhns, Karl [Carl] Christian

Born **Plön, (Schleswig-Holstein, Germany), 22 November 1830**
Died **Leipzig, Germany, 25 July 1881**

Karl Bruhns was a German astronomer and professor who discovered six comets, established an observatory at Leipzig, and made important contributions in advancing meteorology in Germany by introducing a weather prediction service. Bruhns began his career in Berlin as a fitter and mechanic at Siemens & Halske, having been trained as a locksmith, but his primary interest was in astronomy. A professor at Altona recognized his exceptional mathematical skills and recommended him to **Johann Encke**, director of the Berlin Observatory. Following a year-long apprenticeship to Encke, Bruhns was appointed in 1852 as second assistant. He advanced to first assistant in 1854, replacing **Franz Brünnow** when he was recruited as director of the Detroit Observatory at the University of Michigan. By 1856, Bruhns fulfilled university requirements for a doctoral degree with his thesis *De planetis minoribus inter Jovem et Martem circa solem versantibus*.



In 1859, while Bruhns was lecturing at Berlin and also privately, he proposed the construction of a new observatory at Leipzig. The original observatory, located in the tower of an old castle, was dilapidated, and the instruments outmoded. Under his supervision, work commenced in May 1860 on the new observatory, located at the outskirts of town. Bruhns served as the inaugural director, continuing until his death. He was an extraordinary instructor, serving as assistant professor of astronomy at the University of Leipzig beginning in 1861, with promotion to full professor in 1868. An 8-in. equatorial refractor by Pistor & Martins of Berlin, with a Steinheil objective, was added to supplement the observatory's original Fraunhofer refractor and transit circle by Jesse Ramsden. The Leipzig Observatory was destroyed during World War II.

Bruhns had a great interest in meteorology, and organized a meteorological service in Saxony, Germany, in 1863, and a weather prediction service in 1878. He was the discoverer of five new comets (C/1853 R1, C/1855 V1, C/1858 K1, C/1862 X1, and C/1864 Y1) and recovered two comets (5D/Brorsen in 1857 and 4P/Faye in 1858). Among his other contributions, he prepared ephemerides for numerous comets and asteroids, and he observed the solar eclipses of 1867 and 1868 and the transit of Mercury in 1868. Bruhns contributed to American journals including the *Astronomical Journal* and *Astronomical Notices*. He paid tribute to his mentors by writing full-length biographies of Encke (1869) and **Alexander von Humboldt** (1872). In 1989, Bruhns was honored with the naming of a new minor planet, (5127) Bruhns, discovered by E. W. Elst.

Patricia S. Whitesell

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Brünnow, Franz Friedrich Ernst

Born **Berlin, (Germany), 18 November 1821**
Died **Heidelberg, Germany, 20 August 1891**

Franz Friedrich Ernst Brünnow, a German-born and -trained astronomer, was the first European astronomer to be appointed director of an American observatory. He introduced American students to German astronomical methods, which stressed spherical and observational astronomy. Following a brief but distinguished career as director of the University of Michigan's Detroit Observatory from 1854 to 1863, Brünnow served as Astronomer Royal of Ireland and director of the Dunsink Observatory until 1874.

The son of Johann, a German privy councillor of state, and Wilhelmine (*née* Weppler), Brünnow attended the Friedrich-Wilhelm Gymnasium in Trier, Germany, and the University of Berlin, where he studied mathematics, astronomy, and physics. In 1843, upon completion of his thesis, *De Attractione Moleculari*, Brünnow was awarded a Ph.D. degree. As director of the private Bilk Observatory at Düsseldorf, Germany (1847–1851), he wrote an important paper on comet 122P/De Vico, for which he received the Amsterdam Academy's Gold Medal.

In 1851, Brünnow replaced **Johann Galle** as first assistant to **Johann Encke** at the Berlin Observatory, when Galle was appointed director of the Breslau Observatory. Brünnow was trained by Encke as one of a distinguished group of young astronomers that included Galle, **Carl Bremiker**, and **Heinrich d'Arrest**. Brünnow was present in the Berlin Observatory on 23 September 1846 when Galle discovered Neptune based on predictions by French astronomer **Urbain Le Verrier**.

Brünnow met University of Michigan president Henry Philip Tappan when Tappan visited Berlin to purchase instruments for his new campus observatory. Under Tappan's agreement with Encke, Brünnow superintended the construction of a Pistor & Martins meridian circle, and a Christian F. Tiede astronomical clock, both in Berlin shops, to ensure their accuracy before shipment to America. In 1854, Tappan appointed Brünnow as the inaugural director of the Detroit Observatory. Actually located at the University of Michigan in Ann Arbor, the observatory was named to honor its primary benefactors from Detroit. In 1857, Brünnow married Tappan's only daughter, Rebecca Lloyd.

As the first faculty member at the University of Michigan to hold the Ph.D. degree, and the first astronomer to introduce German astronomical methods at an American university, Brünnow's contribution to American higher education in astronomy has been likened in significance to that of Louis Agassiz in natural history. Ann Arbor soon became regarded as the place to study astronomy in America. Brünnow's students in what came to be known as the "Ann Arbor school" of astronomy included **Cleveland Abbe**, **Asaph Hall**, and **James Watson**.

High standards and ideals, extremely hard work, and amazing perseverance characterized Brünnow's academic career. The telescopes under his charge at Michigan, including a 6-in. Pistor & Martins meridian circle and 12 5/8-in. Henry Fitz refractor, lent themselves to the study of double stars, an obsession with Brünnow, and to studies of the motion of asteroids. Brünnow published several asteroid studies, including "The General Perturbations and Elliptical Elements of Vesta" and "Tables of Victoria" (1858) as well as an orbit for the double star 85 Pegasi.

In collaboration with astronomer **Christian Heinrich Peters** of the Litchfield Observatory at Hamilton College in upstate New York, Brünnow established the longitude of the Detroit Observatory in 1861. The astronomical clocks at the two observatories were connected by telegraph to precisely determine the difference in longitude between them. Brünnow then collaborated with the US Lake Survey, based in Detroit, to determine the longitude of an established benchmark in Detroit. That point became the fundamental reference point for all positional determinations made by the Lake Survey in the Great Lakes region.

The University of Michigan's first scholarly journal, *Astronomical Notices*, was created by Brünnow in 1858 and published until 1862. The journal announced discoveries and research findings made at the Detroit Observatory, and published contributions from other notable astronomers. *Astronomical Notices* was created when **Benjamin Gould** barred Brünnow from publishing in the *Astronomical Journal*, which Gould founded and edited. Gould was embroiled in an expansive controversy that ultimately ended in his removal as director of the Dudley Observatory in Albany, New York. Brünnow, who was among the scientists to criticize Gould's development of the observatory, was asked to replace Gould in 1859 as an interim director to establish normal observatory operations. Brünnow quickly succeeded in setting up the Dudley Observatory's fine new telescopes, which he found in their shipping crates when he arrived. He also established a time service for Albany and made longitude determinations. When **Ormsby Mitchel**, the second permanent director of the Dudley Observatory, arrived in Albany in 1860, he and Brünnow clashed. With the added pressure of an urgent call from University of Michigan trustees to return to Ann Arbor, Brünnow resigned from the Dudley Observatory to return to his position as director of the Detroit Observatory.

Shortly after the controversial dismissal of Tappan as president of the University of Michigan in 1863, Brünnow resigned his position as professor of astronomy and director of the Detroit Observatory. The entire family departed for Europe and never returned to the United States. Although Brünnow spent only 9 years in America, he left his mark in the history of American astronomy, and is considered one of the best among a small number of astronomers functioning in America in the mid-19th century.

Brünnow's most important work, *Lehrbuch der spärischen Astronomie* (Handbook of spherical astronomy), was first published in Berlin in 1851. This text established Brünnow as an astronomer of international renown. After leaving the Detroit Observatory, Brünnow translated the text into English in 1865; translations were later published in Spanish, French, Russian, and Italian.

In 1865, Brünnow was appointed Astronomer Royal of Ireland, Andrews Professor of Astronomy in the University of Dublin, and director of the Dunsink Observatory. At Dunsink, he replaced outdated Ramsden transit instruments with a fine Pistor & Martins meridian circle. With that instrument, he then continued the research program on stellar parallax that had been developed by several of his predecessor directors at Dunsink. Brünnow published the parallax results in his *Astronomical Observations* (1870) and *Researches Made at Dunsink* (1873). In 1871, Brünnow collaborated with John Stubbs of Trinity College to expand and update a classic text titled *Brinkley's Astronomy*. In 1869, Brünnow was elected a fellow of the Royal Astronomical Society.

Failing eyesight forced Brünnow to resign in 1874. He retired to Basel then moved in 1880 to Vevey, Switzerland, to be with the Tappans, settling finally in Heidelberg, Germany, in 1889 to be with his son Rudolph after the Tappans' deaths in 1881 and 1884. Brünnow's poor eyesight precluded any scientific work, so he occupied himself through his considerable musical talent. He once remarked that, had he not pursued astronomy, he ought to have devoted himself entirely to music.

Brünnow was making preparations for a trip to Switzerland when he suddenly became ill and died. His death was unexpected, although he had been seriously ill several months earlier. The Brünnows had one son, Rudolph Ernst Brünnow, born in Ann Arbor, who became a distinguished scholar as a professor of Assyriology at the University of Heidelberg, Germany, and later at Princeton University.

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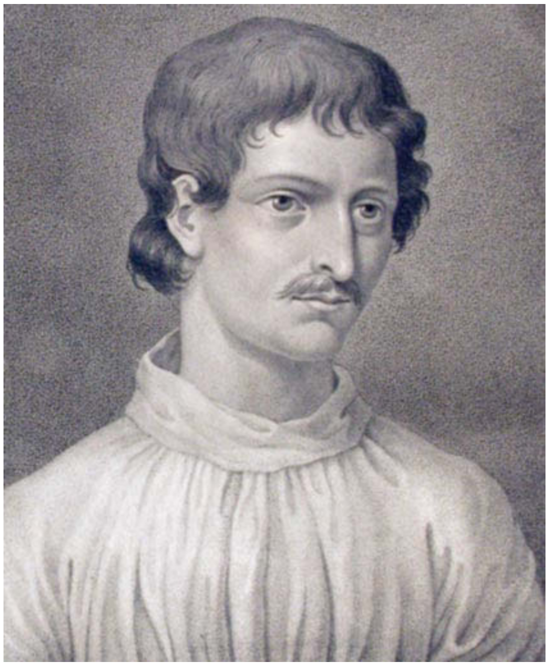
Bruno, Giordano

Born **Nola, (Campania, Italy), 1548**
Died **Rome, (Italy), 19 February 1600**



Although not an astronomer in any technical sense, Giordano Bruno has a place in the history of cosmology because of his outspoken if confused espousal of Copernicanism, and his imaginative pantheistic application of certain aspects of atomism to the cosmos as a whole. He was the first to affirm that stars are suns, and he asserted an infinity of suns accompanied by an infinity of inhabited earths within an infinite Universe.

Bruno was baptized Filippo, but at the age of 15 or 16 he joined the Dominican order and took the name Giordano. He became a priest in the early 1570s and spent some years in Rome teaching the "art of memory," of which he was a master, to students who included Pope Pius V.

After being accused of heresy, Bruno left Rome in 1576 and began 15 years of wandering, spending a year or two in each place he visited and everywhere encountering (or positively inspiring) hostility against his aggressively expressed unorthodox views, mainly on points of religion. In Calvinist Geneva he was threatened with execution in 1579. He moved to Toulouse, where he received a doctorate in theology, then on to Paris in 1581, and to London and Oxford in 1583. But in Oxford, Bruno stirred up more trouble and offense, in response to which he returned to London, where he lived at the house of the French ambassador. During this residency he composed and published his purportedly pro-Copernican dialogue *La cena de le Ceneri* (Ash Wednesday Supper), which contains praise for Queen Elizabeth and ridicule of Oxford, where reigns "a constellation of pedantry, ostentation, ignorance, and presumption" (*Opere It.*, p. 176). In 1585, Bruno returned to Paris and a year later moved on to Wittenberg, but had to leave again in 1588, this time for Prague. In 1589 he moved on to Helmstedt, and in 1590 to Frankfurt. Then he made the fatal mistake of returning to Italy.

For a while, during 1591, he was in Padua, hoping to be offered that university's chair of mathematics, a position in fact filled a year later by **Galileo Galilei**. Late in 1591, Bruno moved to Venice as the guest of a nobleman named Mocenigo, who within a year denounced him as a heretic. So began his incarceration and interrogation by the Inquisition, first in Venice and then, from February

1593, in Rome, where, after a long imprisonment, the unrepentant Bruno was burnt at the stake.

Because of this "martyrdom" to the Inquisition, Bruno has achieved iconic status among many interpreters of the history of science. The loss of thorough records for the period of his final imprisonment has left the field open to speculation concerning the nature of the charges levied against him. What is clear to serious scholars, however, is that Bruno was not a martyr for Copernicanism, despite the continued mythmaking of some popular accounts. The Catholic Church took no official position on **Nicolaus Copernicus** until 1616, 16 years after Bruno's death, when *De revolutionibus* was placed on the *Index librorum prohibitorum*. Moreover, any reader of *The Ash Wednesday Supper* can see how egregiously Bruno mangled Copernicus's theory. In short, if Bruno's fiery execution is no proof that he was a bad theologian, neither does it constitute proof that he was a good scientist.

Debates continue concerning Bruno's true significance. The dominant current in his thought was Hermeticism, a mystical, ultimately pantheistic amalgam of ideas based on the supposedly Mosaic-era writings of Hermes Trismegistus. Bruno uses pantheism's identification of God and cosmos to undermine **Aristotle**'s doctrine of the finitude of the Universe, for:

> it is fitting that an inaccessible divine countenance should have an infinite likeness with infinite parts – such as those countless worlds I have postulated . … There must be innumerable individuals such as those great creatures are (of which our earth is one – the divine mother who gave birth to us, nourishes us, and will finally receive us again into herself). [And] to encompass these innumerable creatures requires an infinite space (*Opere It.,* p. 312; Danielson, p. 142).

Bruno's pantheistic presumption that life is present everywhere in the Universe, combined with his affection for atomism, led him directly to postulate a homogeneous cosmos with stars and earths distributed throughout empty space, and accordingly with no more cosmic center and no more crystalline spheres:

> This entire fantasy of star- and fire-bearing orbs, of axes, of deferent circles, of cranking epicycles – along with plenty of other monstrous notions – is founded merely on the illusory notion that, as it appears, the earth is in the midpoint and center of the universe, while everything else circles about this fixed stationary earth . … [But] this appearance is the same for those who dwell on the moon and on the other stars sharing the same space, be they earths or suns" (*Opere It.,* p. 344; Danielson p. 143).

Bruno's cosmology, therefore, while it can sound as if it anticipates the homogeneous absolute space of **Isaac Newton**, springs from pantheistic assumptions and in fact obviates the need for a mechanical celestial physics. The animated nature of the heavenly spheres is for Bruno sufficient explanation for their behavior. For example, "the moon (which is another earth) moves by her own force through the air about the sun" (*ibid*.). At the same time, such bold speculation about other earths and suns, even if it was purely imaginative, helped to stir the minds of real scientists like **Johannes Kepler**, **John Wilkins**, and **Christiaan Huygens**, whose thoughts of extraterrestrial life were further stimulated by the advent of technology that Bruno never dreamt of: the telescope. Kepler called Bruno's infinitization of the cosmos "that dreadful philosophy." But Bruno did not need to be scientifically acceptable to be scientifically significant.

Dennis Danielson

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Bunsen, Robert Wilhelm Eberhard

Born **Göttingen, (Germany), 31 March 1811**
Died **Heidelberg, Germany, 16 August 1899**

Robert Bunsen's enduring astronomical fame derives not from the Bunsen burner but from his contribution to the development of spectroscopy, the fundamental tool underlying virtually all of the discoveries of modern astronomy. Bunsen's father, Christian Bunsen, was a professor of modern languages at the University of Göttingen. His mother was the daughter of a British–Hanoverian officer. He was the youngest of four sons. After graduation from the Gymnasium at Holzminden, Bunsen studied chemistry at Göttingen, obtaining the doctorate at the age of 19. From 1830 to 1833, he traveled extensively, aided in part by a grant from the government of Hanover, and established scientific contacts that he would nurture for decades. His experiences included visits to factories, tours, and periods of study at laboratories of leading German and Parisian chemists, field trips with geologists, and exposure to geological collections.

In 1833, Bunsen became a *Privatdozent* (lecturer) at the University of Göttingen. After a brief stint teaching at the Polytechnic School in Kassel from 1836 to 1838, he would affiliate with German university culture for the rest of his working career as a professor of chemistry at Marburg (1838–1852) and Heidelberg (1852–1889).

A lifelong bachelor, Bunsen centered his life around his laboratory and his students. He traveled widely alone and with friends. His professional colleagues honored his scientific achievements with election to the Chemical Society of London (1842), and appointments as corresponding member of the Paris Académie des sciences (1853) and later as foreign member (1882) and as foreign fellow of the Royal Society of London (1858). Bunsen received the Copley Medal of the Royal Society of London (1860), the first Davy Medal (1877), and the Albert Medal of the English Society of Arts (1898) in recognition of his scientific contributions to industrial technology.

Bunsen researched primarily in the areas of inorganic and analytical chemistry. He also did important work in organic chemistry in the 1830s and 1840s, maintained an interest in geological research throughout his working life, and applied his scientific expertise to improve blast-furnace efficiency and galvanic currents in batteries.

Bunsen's dramatic impact on astronomy stemmed from his essential contributions to the fledgling science of spectroscopy in the late 1850s and early 1860s. In 1859, his Heidelberg physicist colleague **Gustav Kirchhoff** explained the phenomenon of dark lines in the solar spectrum as absorptions of light of the same wavelengths that materials in the path of the light emit when heated or sparked. The two men recognized that analyses of emission and absorption spectra could indicate compositions of terrestrial and celestial substances. It was now possible to determine what the Sun and stars were made of with the same accuracy as chemical analyses would provided.

Bunsen and Kirchhoff found that the study of light emitted by substances required a high-temperature, nonluminous flame. In the 1850s, Bunsen had improved earlier burner designs by Ami Argand and Michael Faraday to devise a means of premixing the gas and air before combustion that produced a flame of minimal colorization. The Bunsen burner was actually constructed by Peter Desaga, a technician at the University of Heidelberg, based on Bunsen's idea. It proved to be an effective tool for exposing the characteristic colors of light emitted by substances.

Together with Kirchhoff, Bunsen invented the spectroscope in 1859. The first model was little more than a prism within a cigar box into and out of which protruded ends of two old telescopes. The men observed colors emitted by various materials placed in the flame of the Bunsen burner and then dispersed through the prism. They were able to identify those colors characteristic of known chemical elements and to affiliate other colors with previously unknown elements. Using the spectroscope, they discovered cesium (1860) and rubidium (1861). Only trace amounts of elements in small samples were necessary for spectral identification. For example, cesium was detected in a few drops of the alkaline residue from an analysis of mineral water; 40 tons of mineral water later was required to yield the several grams of cesium chloride necessary to determine the physical and chemical properties of the new element.

A succession of elemental discoveries enabled by the spectroscope ensued over the next two decades, including the controversial claim in 1868 by **Norman Lockyer** and Edward Frankland of a new element in the Sun's chromosphere that Lockyer dubbed "helium." The line in the solar spectrum that supported this claim had been observed independently by **Pierre Janssen** and Lockyer in 1868. This remained the only evidence for the element helium until **William Ramsay** and his coworkers isolated it from various minerals and mineral waters in the 1890s and determined its physical and chemical properties. Meanwhile, the rapid exploitation of photography to record spectra permanently for study and comparison opened up unprecedented opportunities for astronomers to determine the material constituents of the Sun and stars in the late 1800s.

Robert K. DeKosky

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Buot [Buhot], Jacques

Born **L'Aigle, (Orne), France, before 1623**
Died **Paris, France, January 1678**

Jacques Buot was an engineer, mathematician, astronomer, and physicist. Little is known about the life of Buot. He was probably a gunsmith in L' Aigle, before moving to Paris on the advice of **Pierre Petit**, the civil engineer in charge of the French fortifications, and of Jean Balesdens, secretary and friend of Chancellor Séguier. Buot was described as *Mathématicien* (1647), *Ingénieur ordinaire du Roi* living in Paris at the Tuileries (1648) and staying at Montmor's mansion (1649), *Cosmographe, ingénieur ordinaire du roi et maître aux mathématiques de Monseigneur le Dauphin* (1670, according to contemporary manuscripts drawn up by solicitors or Roman Catholic priests), and finally *Ingénieur du Roi, professeur de mathématiques des Pages de la Grande Écurie*. Buot was one of the original seven members of an assembly of "mathematicians," which was to become part of the Académie royale des sciences. He had been chosen in about May 1666 by J. B. Colbert together with Pierre de Carcavi, **Christiaan Huygens**, Gilles Personne de Roberval, Bernard Frénicle de Bessy, **Adrien Auzout** and **Jean Picard**. The appointment brought with it a salary of 1,200 livres per year. Although M. J. A. Condorcet gave Buot's death year as 1675, Buot was alive in December 1677 but very ill; **Philippe de la Hire** was appointed to the academy in his stead on 26 January 1678, so we know that Buot was dead by then.

Except for correspondence with advocates like Petit and Balesdens, the first mention of Buot occurs in 1647 when he published his *Usage de la roue de proportion …, avec un traité d'arithmétique*, dedicated to Chancellor Séguier. This publication shows that Buot could rank with Edmond Gunter and Blaise Pascal as one of the first inventors of calculating machines. As a mathematician, Buot left several memoirs in the *Procès verbaux* of the academy on the "Limaçon de Mr Pascal," a treatise about "les lieux géométriques," and answers to several geometrical questions.

As a physicist Buot was involved in many mechanical experiments including studies of the strength and expansion of metals like copper, iron and steel, studies of samples of magnetic materials, and experiments on forces such as gravity, the so-called centrifugal force, friction, and capillarity. The academy often requested his expert advice on tests of metals, alloys, solders, or object-glasses, to check on the correctness of maps, to provide instructions for the making of celestial globes, and to prepare reports such as those on lifting appliances and, not surprisingly, on the efficiency of different guns. In June 1675, he was asked to draw up a descriptive catalog of the instruments held by the academy. Together with François Blondel and Picard, he was an executor of the will of Roberval.

The first mention of Buot as an astronomer occurred in the *Astronomica Physica*, published by J.-B. du Hamel in 1660, where observations of the solar eclipse of 8 April 1652 made by Buot, Petit, J. A. Le Tenneur, and Auzout in Paris are reported. In the *Journal des Sçavans*, of 26 January 1665, Buot's *Carte du Ciel*, made by order of the king, is described. This map showed the constellations through which passed the orbit of comet C/1665 F1. Buot's own observations of the comet were included with the map. Other achievements appeared in the *Procès verbaux* of the academy (with a gap between 1670 and 1674): a memoir on the projection of topographical maps in 1666; observations of the elevation of the celestial pole made at the end of 1666 by means of a sextant with a radius of 6 ft.; and a method for finding the positions of the fixed stars in 1667. From 1666 onward Buot took part in the routine operations of the academy. These included the observation of the solar eclipse of 2 July 1666 made by Buot, Huygens, Carcavi, Roberval, Auzout, and Frénicle from Colbert's house, where the academy met; the marking of a meridian line on a stone at Paris Observatory on 21 June 1667 (the day of the summer solstice); and the observation of Saturn on 16 July 1667, from which he calculated the inclination of the planet's ring to the ecliptic as 31° 38′ 35″ (correcting Huygens's 1659 value), and that of 15 August 1667 carried out with Huygens, Picard, and **Jean Richer** from which he calculated the value of 32° 0′, and 9° 32′ 50″ for the inclination to the Equator. The *Journal des Sçavans* of 21 March 1672 reported the observation of a "great permanent spot" on Jupiter, which **Jean Dominique Cassini** had observed in 1665, but had not seen since the beginning of 1666. The reappearance of the same spot on 19 January 1672 and Cassini's calculations to predict its position for 3 March motivated the academy to ask Buot and Edme Mariotte to assist Cassini at the Paris Observatory. Their observations confirmed the period of Jupiter's rotation as 9 h and 56 min.

In 1667 Buot invented the *Équerre azimutale*, precisely described and illustrated in the first volume of the *Machines et inventions approuvées par l'Académie royale des sciences* (not printed until 1735). Made of copper, the instrument enabled an observer to lay out an accurate meridian line without exact knowledge of the time of local noon. Claude Antoine Couplet, also *ingénieur ordinaire du Roi et professeur royal de mathématiques des Pages de sa Grande Écurie* and former student of Buot (and who married Buot's stepdaughter Marie Baillot), assisted in the construction of the instrument.

Françoise Launay

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Burckhardt, Johann Karl [Jean-Charles]

Born **Leipzig, (Germany), 30 April 1773**
Died **Paris, France, 21 June 1825**

Johann Karl Burckhardt (known in France as Jean-Charles) is best known for his contributions to **Joseph-Jérôme Lalande**'s catalog of 50,000 stars and for carrying out calculations based upon **Pierre de Laplace**'s theories for the ephemerides of the

Bureau des longitudes. Burckhardt studied mathematics in Germany and applied his knowledge to eclipse computations and to longitude determinations using lunar occultations. When Baron **János von Zach** was in search of an astronomer for his Gotha Observatory (Seeberg), Burckhardt was recommended to him, and he was hired to work on practical astronomy and to observe star transits. In France, Lalande had undertaken a similar search for the Observatoire de l'École militaire, of which he was director. In August 1797, Zach requested Lalande to have Brurkhardt placed at the Collège de France, his pension being paid by the Duchesse de Gotha.

Burckhardt arrived in Paris at the end of 1797. As a linguist, he was eager to study current astronomical publications in their original form. He translated the first two volumes of Laplace's *Mécanique céleste* while reading the proofs; he also added some notes and double-checked the calculations, made by **Alexis Bouvard**. On various occasions Lalande praised Burckhardt for being a tireless observer, rapid calculator, and a translator making French science known in Germany. In Paris, Burckhardt worked for both the Observatoire de l'École militaire, where he resided, and the Bureau des longitudes. He published, in 1817, *Table des diviseurs de tous les nombres du premier million ... avec les nombres premiers qui s'y trouvent*. At the observatory of the École militaire, he actively participated in finalizing the catalog to which Lalande's nephew, **Michel Lefrançois** and his wife, Amélie Harlay (one of the very few women astronomers of the time), were already engaged. The observations went up to 1 April 1801. In the same period, Burckhardt established a quick method for calculating the orbit of a comet given limited data, a method applied successfully to the orbit of the first asteroid discovered, by **Giuseppe Piazzi**, on 1 January 1801. In 1808, Burckhardt took an interest in the *force de la lumière*, as it was named by **Pierre Bouguer**, and he designed an instrument combining a heliometer with a photometer. The Bureau des longitudes appointed him as *astronome adjoint* upon his naturalization in 1799. At the Bureau, Burckhardt worked out lunar tables, employing more than 4,000 observations. A commission, comprised of Bouvard, **Jean-Baptiste Delambre**, and Laplace, examined the results in 1811, and Laplace found that their errors were smaller than those of J. T. Bürg; they were soon in use for French ephemerides.

Burckhardt himself participated in later commissions as an expert on instruments (including comparisons for meters and kilograms in the new metric decimal system of weights and measures), to the reception of manuscripts from Delambre, **Pierre Méchain**, and Lefrançois related to the measurements of the *Méridienne de France*, and to examine the sector employed by **Pierre de Maupertuis** when in Lapland. Later, in 1819, with Bouvard and **Francois Arago**, he tested one of Lerebours' refractors, having a focal length of 6 m and an aperture of 20 cm. At that time Arago wanted such a powerful instrument for the Paris Observatory, though he would not be successful for 25 years.

Burckhardt published a number of papers, including one on Piazzi's discovery. By 1817, he became a full member of the Bureau des longitudes. From 1804, he had been a member of the astronomical section in the first class of the Institut de France, which had replaced the old Académie royale des sciences.

Solange Grillot

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Bürgi, Jost [Joost, Jobst]

Born **Lichtensteig, St. Gallen, Switzerland, 28 February 1552**
Died **Kassel, (Hessen Germany), 31 January 1632**

Jost Bürgi was a clock maker, astronomer, and applied mathematician. His father was probably a fitter. Very little seems to be known about his life before 1579. It is probable that Bürgi obtained much of his knowledge in Strassburg, one of his teachers being the Swiss mathematician Konrad Dasypodius. An indication that he did not get a systematic education is the fact that Bürgi did not know Latin, the scientific language of his time. Nevertheless, he made lasting scientific contributions that prompted some biographers to call him the "Swiss Archimedes." Bürgi was married first to the daughter of David Bramer, then in 1611, married Catharina Braun.

Bürgi developed a theory of logarithms independently of his Scottish contemporary **John Napier**. Napier's logarithms were published in 1614; Burgi's were published in 1620. The objective of both approaches was to simplify mathematical calculations. While Napier's approach was algebraic, Bürgi's point of view was geometric. It is believed that Bürgi created a table of logarithms before Napier by several years, but did not publish it until later in his book *Tafeln arithmetischer und geometrischer Zahlenfolgen mit einer gründlichen Erlüterungen, wie sie zu verstehen sind und gebraucht werden können*. Indications that Bürgi knew about logarithms earlier in 1588 can be obtained from a letter of the astronomer **Nicholaus Bär** (Raimarus Ursus), who explains that Bürgi had a method to simplify his calculations using logarithms.

Logarithms paved the way for slide rules because the identity $\log(a \cdot b) = \log(a) + \log(b)$ allows one to compute the product of two numbers a and b as an addition. Bürgi also computed sinetables. These tables, called *Canon Sinuum*, seem however to have been lost. The sinetables were used in a method called *prosthaphaeresis*, known to many astronomers in the 16th century. In this method, trigonometric formulas like $\sin(x)\sin(y) = [\cos(x-y) - \cos(x+y)]/2$ are used to reduce multiplication to addition. Bürgi is considered as one of the inventors of that method; other identities were used by Ursus, **Johannes Werner**, and **Paul Wittich**.

Another indication that Bürgi's discovery of logarithms was independent of Napier's is the fact that **Johannes Kepler**, who admired Bürgi as a mathematician, states in the introduction to his *Rudolphine Tables* (1627):"… the accents in calculation led Justus Byrgius on the way to these very logarithms many years before Napier's system appeared; but being an indolent man, and very uncommunicative, instead of rearing up his child for the public benefit he deserted it in the birth." Although the two discoveries are today believed to be independent, Napier definitely enjoyed the right of priority in publication.

Both methods were mainly computational. It seems that the first clear and theoretical exposition of the equation log(x y) = log(x) + log(y) can be found in Kepler's *Chilias logarithmorum*.

In 1579, Bürgi entered the employ of Landgrave **Wilhelm IV** of Hesse-Kassel, observing with the court-mathematician **Christoph Rothmann** at the excellent Kassel Observatory. Some denote it as the first stationary observatory in Europe. Bürgi, who also knew **Tycho Brahe** and who was a friend of Kepler, made many instruments for the observatory. One of the instruments was the "reduction compass," another being the "triangularization instrument," both of which had military applications. Bürgi's famous celestial globe from 1594 can be seen on some Swiss stamps.

Bürgi is credited with the invention of the minute hand on clocks in 1577. His invention was part of a clock he constructed for Brahe, who needed precise time for observing. Bürgi is also known in the history of time measurement for a clock he made in 1585 that would run for 3 months. He introduced the idea of adding an independent system to the traditional wheel-train, which was wound in short periods by the mainspring, giving a more constant flow to the escapement. This was later perfected, leading eventually to an autonomy of several months. In 1604, Bürgi became court watchmaker to Emperor Rudolf II. He returned to Kassel the year before his death.

Oliver Knill

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Buridan, John

Born **Diocese of Arras, Picardy, France, *circa* 1300**
Died **1358–1361**

John Buridan was one of the most influential philosophers of his time, who, after William Ockham, was primarily responsible for the emergence of the nominalist *via moderna*, the "modern way" of dealing with theoretical matters. He also contributed the idea of impetus to account for motion.

We know relatively little about Buridan's life. He was born around 1300 in the diocese of Arras, in Picardy, and completed his early education in the College of Cardinal Lemoine, where he may have been a recipient of a stipend for needy students. He obtained his license to teach, sometime after 1320 at the Arts Faculty of the University of Paris, where he taught for the rest of his life as Master of Arts. Buridan was twice elected rector of the University of Paris, in 1327/1328 and 1340, and became a highly respected, influential public figure. He was unusually well-off for a university professor, drawing income from at least three benefices. His students, radiating from Paris to the newly established universities of Europe, widely disseminated his nominalist doctrine. Buridan may have died in the plague of 1358, but he certainly did not live after 1361, when one of his benefices went to another person.

In accordance with the requirements of philosophy teaching of the time, Buridan's works – besides some independent treatises in logic (in particular, the *Treatise on Consequences*, and the monumental *Summulae de Dialectica*) – primarily consist of commentaries on **Aristotle**'s works, ranging from logic to metaphysics, natural philosophy, ethics, and politics. The question format, raising and thoroughly discussing major problems in connection with Aristotle's text, allowed Buridan to develop a comprehensive nominalist philosophical system, putting to consistent use the analytic conceptual tools he worked out in his logical treatises. These conceptual tools allowed him to provide meticulous analyses of the technical language of Aristotelian science, and to tackle traditional scientific problems in innovative ways. Thus, for instance, he presented an analysis of time as being simply the number of the revolutions of the sphere of the fixed stars connoted in various ways by our concepts. This of course does not mean that time is a matter of subjective experience, since the revolutions of the outermost sphere are real regardless of whether there is a human mind to count them. Still, this number is only time if it is connoted by appropriate temporal concepts: As Buridan put it, were there no human minds forming concepts with such a connotation, the thing that is time would still exist, but it would not be time.

But Buridan's most lasting contribution to physics in general, and to astronomy in particular, was his theory of *impetus*, which had a significant role in eventually dismantling the Aristotelian paradigm.

Buridan primarily introduced the notion of *impetus* to account for the motion of projectiles. The commonly accepted principle held that whatever is in motion needs a mover to sustain its motion. On the basis of this assumption, the question of what moves projectiles, such as an arrow when it is no longer moved by the bowstring, naturally emerged. Aristotle's reply, that it is the air set in motion by the original mover, was heavily criticized by Buridan on the basis of careful observation, further analysis – if the air moves the projectile, what moves the air – as well as the analogous consideration of other types of motion, such as the ongoing rotation of a spinning wheel, which certainly cannot be explained by the motion of the surrounding air. Similar considerations apply to large bodies set in motion but no longer moved, such as a ship, which is very hard to stop, yet it is obviously not moved by the surrounding air.

Accordingly, Buridan assumed that these motions must be explained by an impressed force, the *impetus*, which is left behind in the moving body by the mover. This force is directly proportional to the heaviness of the moved body and its speed; it is decreased by resistance, and increased by the ongoing activity of the mover, but remains the same if the body once set in motion is left alone. Thus, Buridan's theory correctly predicted that a body set in motion but left alone will exhibit what modern physics would describe as inertial motion. Accordingly, contrary to Aristotle, Buridan should not find the hypothesis of the Earth's daily rotation absurd, since, for example, by his theory's predictions the alleged absurdity of an arrow shot directly upward never falling back in the same place should not follow. However, when he actually analyzed this problem, he found Aristotle's example about the arrow "more demonstrative" than the arguments of those who were willing to maintain the hypothesis of the rotation of the Earth. Apparently, in this argument Buridan simply failed to take into account the "lateral impetus" the arrow already has on account of the Earth's movement, which, however, would have to be taken into account based on his principles.

On the basis of the same principles, Buridan was able to account for the acceleration of falling bodies in terms of the growing intensity of their *impetus*. However, he was also committed to assigning greater acceleration to heavier bodies. But in general, Buridan's theory remained on the level of qualitative explanation, without enabling predictions of quantifiable results that could be tested by measurements in experiments.

Nevertheless, Buridan's theory still had the tremendous significance of providing a unified explanation for the phenomena of very different motions that had been classified differently in the traditional Aristotelian system. It was precisely this unifying perspective of Buridan's theory that enabled him to treat celestial motions and sublunary motions in accordance with the same mechanical principles. Accordingly, in his questions on Aristotle's *Physics*, Buridan argued that, since we have no Biblical reason to assume the existence of the celestial intelligences (angels) traditionally assigned to move the heavenly spheres, celestial motions could be explained by an initial *impetus* given to these spheres by God, since they have no other natural inclination, and there is no resistance to their rotation. Buridan did not mention that this solution immediately invalidated the Aristotelian argument for the existence of a presently existing and active prime mover, that is, God. But he certainly was aware that these speculations took him dangerously close to questions to be determined in the Faculty of Theology. So he immediately remarked that he did not want to assert this position, but rather left the determination of the issue to theologians.

These speculations once and for all opened up the possibility of a unified mechanics, based on the same principles for earthly and celestial motions. Perhaps this was the most important "change in perspective" in medieval astronomy provided by Buridan's theory, pointing in the direction of early modern celestial mechanics.

Gyula Klima

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Burnham, Sherburne Wesley

Born **Thetford, Vermont, USA, 12 December 1838**
Died **Chicago, Illinois, USA, 11 March 1921**

Sherburne Burnham, the leading discoverer, observer, and cataloger of double stars in the late 19th and early 20th centuries, was the son of Roswell O. and Marinda (*née* Foote) Burnham. Educated only in the local district school and the Thetford Academy, Burnham received no formal postsecondary education. For most of his life, Burnham was an amateur astronomer in the sense that he did not earn his living by his astronomical work. After completing his schooling, he acquired knowledge of shorthand and was employed by a stenographic recording firm in New York City. That employment apparently involved a trip to Europe, for while in London in 1861, Burnham acquired his first telescope, a 3-in. refractor on a simple tripod.

During the US Civil War, Burnham was an official reporter with the Union troops in New Orleans. Burnham's interest in astronomy was sparked by the chance purchase of a book, L. Burritt's *Geography of the Heavens*, while he was still serving in New Orleans. In 1866, Burnham moved to Chicago and became a court reporter, having already exchanged the 3-in. refractor for a 3.75-in. equatorially mounted Fitz refractor. A second book acquired for his early astronomical library, a copy of Reverend **Thomas Webb**'s *Celestial Objects for Common Telescopes*, apparently stimulated Burnham's interest in double stars. The inadequacies of the Fitz telescope soon became evident to him. In 1869, Burnham commissioned a 6-in. refractor from Alvan Clark & Sons. He specified that **Alvan Clark** should take whatever time was necessary to make a telescope with "definition as perfect as they could make it" for his use in studying double stars, but otherwise left the details of the telescope design to Clark. With this instrument, delivered by Clark in 1870, Burnham discovered 451 previously unknown visual binary stars. All his subsequent discoveries were also made with instruments made by the Clarks.

From 1876 to 1884, Burnham had access to the 18.5-in. refractor of the Dearborn Observatory. Although he continued to earn his living by his work in the courts, Burnham served as the acting director of the Dearborn Observatory from 20 September 1876 until 11 April 1877. An unfortunate dispute with the observatory board of directors cut short what might otherwise have been a beneficial arrangement for the observatory. Burnham eventually continued to use the Dearborn refractor for his double-star observations and, as **Philip Fox** pointed out in his history of the Dearborn Observatory, Burnham's 413 double-star discoveries constitute the only evidence of productive scientific use of this telescope prior to the arrival of **George Hough** as the Dearborn Observatory director in 1879.

Burnham was also associated with the then new Washburn Observatory of the University of Wisconsin. **Edward Holden**, later to become director of the Lick Observatory, was the Washburn director at the time. In 1881, Holden induced Burnham, who was by then quite famous for his work in double-star astronomy, to come to Madison and work as a professional astronomer. Burnham remained in Madison for a year, during which time he observed with the Washburn Clark 15.5-in. refractor and, to his later regret, sold his own 6-in. Clark refractor to the observatory. Burnham apparently decided he was not yet ready for a change of profession and returned to his regular employment as a court recorder in Chicago.

In 1888, Holden offered Burnham a position at the newly opened Lick Observatory. Burnham accepted that position with alacrity even though it probably meant a considerable reduction in salary. Burnham had already observed from Mount Hamilton on two earlier occasions. In 1879, he conducted a site evaluation for the Lick Trustees with his 6-in. Clark refractor. He returned to Mount Hamilton in 1881 to observe the transit of Mercury. Thus, Burnham was well aware of the superior atmospheric conditions that favored astronomical observation from Mount Hamilton.

By 1892, however, as **Edwin Frost** delicately phrased it, "internal conditions developed at the observatory which were not agreeable to Mr. Burnham." Holden's acrimonious disputes with Burnham, and with other astronomers at the Mount Hamilton, are well documented in the history of the Lick Observatory. Burnham resigned and returned to Chicago to become clerk for the US District Court, a position he held until 1902. Until 1897, Burnham could make only occasional visits to the Dearborn Observatory, but he continued to work on the computation of orbits and the preparation of a general catalog of double stars.

In 1897, **George Hale** appointed Burnham professor of practical astronomy at the University of Chicago, in anticipation of the installation of the 40-in. refractor. Beginning in October of that year, Burnham was assigned two nights a week on the 40-in. refractor. Because of his court duties, those two nights were of Saturday and Sunday. Burnham would arrive on Saturday afternoon, get what sleep he could on Sunday, and return to Chicago by the early-morning train on Monday. At this stage, he gave up searching for new pairs, and concentrated on measuring those already known. In the course of a good night, he could measure 100 pairs. In this last period, he also used the telescope to measure proper motions. His last observation with the 40-in. refractor was made on the night of 13 May 1914.

Burnham must have been gifted with extraordinarily good eyesight. He could recognize doubles that had eluded detection by others, and he could make measurements of high precision, even of pairs that were difficult to resolve. Burnham's best measures were probably the finest made before the advent of speckle interferometry. Up to the time of his observations, it was generally believed that others, principally **Friedrich, Gustav, Karl,** and **Otto Wilhelm Struve,** had already discovered most of the existing double stars. By discovering approximately 1,300 new pairs, Burnham showed that many more remained to be discovered and ushered in a new era of double-star astronomy. The importance of Burnham's discoveries resides not only in their quantity, but also in the fact that most of the Burnham double stars are of shorter periods. The shorter periods facilitated computation of more orbits than had previously been known. This, in turn, contributed substantially to our early understanding of the masses of stars.

In 1900, Burnham dedicated a catalog of his own discoveries to the Hungarian–Italian amateur and observer of double stars, Baron **Ercole Dembowski**, who helped and encouraged Burnham by measuring many new pairs before Burnham himself was equipped to do so. Later, Burnham also prepared and published a two-volume catalog of all known double stars in the northern sky, which immediately became a standard reference work. Even after **Robert Aitken** published a revised version in 1932, Burnham's catalog continues to be a useful reference work. Burnham also devised an improved method of illuminating the cross-wires of a filar micrometer, which was adopted by many other observers.

Burnham married Mary Cleland in 1868, and they had three sons (Augustus, Raymond, and Harold) and three daughters (Marion, Lida, and Grace). Later in life, he was awarded an honorary A.M. by Yale University in 1878 and an honorary Sc.D. by Northwestern University in 1915. Burnham received the Gold Medal of the Royal Astronomical Society in 1894 and was elected an associate of that Society in 1898. He was awarded the Lalande Prize of the Paris Academy of Sciences in 1904. He was an associate fellow of the American Academy of Arts and Sciences.

Burnham's two great hobbies were photography and bowling. He often took photographs of others but apparently disliked having his own taken; a photograph of Burnham is a rarity. Many people who knew him because of one or the other of these hobbies were unaware of his singular achievements as an astronomical observer.

Alan H. Batten

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Burrau, Carl

Born **Helsingör (Elsinore), Denmark, 29 July 1867**
Died **Copenhagen, Denmark, 8 October 1944**

In collaboration with **Svante Strömgren**, Danish mathematician Carl Burrau investigated a three-body problem in which two of the masses are equal and revolve about each other in circular orbits. His collaboration with **Törvald Thiele** on the three-body problem, and their method of numerical transformations for this work, is frequently known as the Thiele–Burrau method.

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Būzjānī: Abū al-Wafā' Muḥammad ibn Muḥammad ibn Yaḥyā al-Būzjānī

Born **Būzjān (Būzhgān, Khurāsān, Iran), 10 June 940**
Died **Baghdad, (Iraq), 997 or 998**

Būzjānī was one of the leading astronomers and mathematicians of the Middle Ages, with significant contributions in observational astronomy. His achievements in trigonometry paved the way for more precise astronomical calculations.

Būzjānī was born in Būzjān, in the region of Nīshāpūr. The town is now a deserted land in the vicinity of the small town of Torbat-i Jām, located today in the Iranian province of Khurāsān. He was from an educated and well-established family. He is said to have studied arithmetic under both his paternal and maternal uncles.

Būzjānī flourished in an age of great political upheavals. The Būyids (945 to 1055), a family originally from the highlands of Daylam in northern Iran, had built a new dynasty that soon extended its rule over Iraq, the heart of the ʿAbbāsid caliphate, reducing the caliph's rule to a mere formality. Under the Būyids, who were great patrons of science and the arts, many scientists and scholars were attracted to Baghdad to enjoy the benefits of the new rulers' patronage. The change in the political climate had brought with it a great cultural revival in the eastern Islamic lands promoting literary, scientific, and philosophical activities on a grand scale.

At the age of 20, Būzjānī moved to Baghdad, the capital of the ʿAbbāsid caliphate, where he soon rose to prominence as a leading astronomer and mathematician at the Būyid court, conducting observations and research in the *Bāb al-Tibn* observatory. The decade following 975 seems to have been his most active years in astronomy, during which he is said to have conducted most of his observations. Later, to comply with the wishes of Sharaf al-Dawla, the Būyid Amīr (Regent), who was himself a learned man with keen interest in astronomy, Būzjānī became actively involved in the construction of a new observatory in Baghdad. His collaborator was **Kūhī**, another celebrated astronomer from the northern part of Iran who at the time was unrivaled in making astronomical instruments. The astronomical work of Būzjānī and his colleagues in Baghdad mark the revival of the "Baghdad school," a tradition with much vitality in the preceding century.

Bīrūnī, the renowned astronomer and scientist living in Kath (in central Asia), tells us of his correspondence with Būzjānī, who was in Baghdad. This correspondence, and the exchange of astronomical data and measurements between them, signifies not only their mutual recognition as the leading astronomers of the time, but also the vigor with which astronomical observations were carried out in those days. According to Bīrūnī, in 997 the two astronomers prearranged to make a joint astronomical observation of a lunar eclipse to establish the difference in local time between their respective localities. The result showed a difference of approximately 1 hour between the two longitudes – very close to present-day calculations. In addition to this, Bīrūnī makes numerous references to Būzjānī's measurements in his various works.

Būzjānī's principal astronomical work, and his sole extant writing on the subject, is *Kitāb al-Majisṭī*. The book consists of three chapters: trigonometry, application of spherical trigonometry to astronomy, and planetary theory. An incomplete manuscript of this work exists in the Bibliothèque nationale, Paris.

A misinterpretation of a part of this book led Louis A. Sedillot (the French scientist) to claim that credit for discovering the variation (the third inequality) of the Moon's motion belonged to Būzjānī, and not to **Tycho Brahe**. This gave rise to a long-lived debate in the French Academy of Science from 1837 to 1872. The case was finally resolved by Carra de Vaux, the prominent historian of science in Islam, who, after a thorough study of the manuscript in 1893, reasserted Brahe's right to this discovery.

Although Būzjānī's *al-Majisṭī* – at least judging from the extant portion – did not introduce considerable theoretical novelties, it did contain observational data that were used by many later astronomers. More importantly, its section on trigonometry was a comprehensive study of the subject, introducing proofs in a masterly way for the most important relations in both plane and spherical trigonometry. Būzjānī's approach, at least in some instances, bears a striking resemblance to modern presentations.

In *al-Majisṭī*, Būzjānī introduced for the first time the tangent function and hence facilitated the solutions to problems of the spherical right-angled triangle in his astronomical calculations. He also devised a new method for constructing the sine tables, which made his tables for sin 30′ more precise than those of his predecessors. This was an important advance, since the precision of astronomical calculations depends upon the precision of the sine tables. The sine table in Būzjānī's *Almagest* was compiled at 15′ intervals and given to four sexagesimal places. In the sixth chapter of *al-Majisṭī*, Būzjānī defines the terms tangent, cotangent, sine, sine of the complement (cosine), secant and cosecant, establishing all the elementary relations between them. Then assuming the radius of the (trigonometric) circle $R = 1$, he deduces that the tangent will be equal to the ratio of the sine to the sine of complement, and the inverse for the cotangent (identical to our present terminology). Later, Bīrūnī, inspired by Būzjānī and for simplification, uses this norm of $R = 1$ instead of $R = 60$ which was up until then commonly used in compiling the tables.

Būzjānī's contributions to mathematics cover both theoretical and practical aspects of the science. His practical textbook on geometry, *A Book on Those Geometric Constructions Which Are Necessary for a Craftsman*, is unparalleled among the geometrical works of its kind written in the Islamic world. Būzjānī wrote a practical textbook on arithmetic as well. The book is entitled *Book on What Is Necessary from the Science of Arithmetic for Scribes and Businessmen*. This is apparently the first and only place where negative numbers have been employed in medieval Islamic texts.

On the basis of works attributed to him, Būzjānī seems to have been a prolific scholar. He is said to have written 22 books and treatises. These include works on astronomy, arithmetic, and geometry, as well as translations and commentaries on the algebraic works of past masters like Diophantus and **Khwārizmī**, and a commentary on Euclid's *Elements*. Of all these works, however, only eight (as far as we know) have survived. Of his astronomical works, references were made to a *Zīj al-wāḍiḥ*, an influential work that is no longer extant.

Historical evidence, as well as the judgments of Būzjānī's colleagues and generations of scholars who came after him, all attest to the fact that he was one of the greatest astronomers of his age. He was also said to have been a man with great moral virtues who dedicated his life to astronomy and mathematics. His endeavors in the domain of science did not die with him. In fact, the data Būzjānī had gathered from his observations were used by astronomers centuries after him. Furthermore, the science of trigonometry as it is today is much indebted to him for his work. In his honor and to his memory, a crater on the Moon has been named for Būzjānī.

Behnaz Hashemipour

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Byrd, Mary Emma

Born **Le Roy, Michigan, USA, 15 November 1849**
Died **Lawrence, Kansas, USA, 30 July 1934**

Mary Byrd directed the Smith College Observatory, determined the positions of comets by photographic astrometry, and pioneered the development of laboratory teaching methods in descriptive astronomy.

Byrd's father was an itinerant Congregational minister, the Reverend John Huntington Byrd; her mother was Elizabeth Adelaide Low. After age six, Byrd grew up in Kansas and later attended Oberlin College and the University of Michigan, where she earned an A.B. degree (1878). After four years as a teacher and a high-school principal, Byrd spent a year as a voluntary assistant at the Harvard College Observatory, under **Edward Pickering**. Between 1883 and 1887, she taught mathematics and astronomy at Carleton College, Northfield, Minnesota, and operated its time service under the supervision of **William Payne**. Byrd later earned her Ph.D. in astronomy at Carleton (1904). Like many women who chose to pursue a scientific career in that era, Byrd never married.

In 1887, Byrd accepted the directorship of the Smith College Observatory, Northampton, Massachusetts. For nineteen years, she trained young women in science and developed laboratory methods of teaching descriptive astronomy (as opposed to standard lecture/recitation procedures). These were highlighted in Byrd's *Laboratory Manual of Astronomy* (1899) and her *First Observations in Astronomy* (1913). An astute observer of changing educational practices and the declining influence of the liberal arts college's classical curriculum, Byrd sought to place her subject on the same level as the new experimental subjects of physics and chemistry within the nation's emergent research universities. Her own astronomical research concerned the photographic determination of the positions of comets.

Collapse of the mental discipline model of pedagogy and the reduction of astronomy from a college prerequisite to an elective subject carried important implications for astronomy instructors in the years after 1900. Recognizing that a crucial link in the cycle of astronomy teaching and learning had been severed and must be reforged, Byrd looked to the nation's normal schools as the place from which to recruit astronomy-literate teachers. She wrote prolifically to try and bridge apparent gaps in the pedagogical literature.

Byrd abruptly resigned her position in 1906 after she learned that Smith College had agreed to accept financial support from Andrew Carnegie. Believing that such a decision severely compromised her institution's freedom of expression, she undertook this action as a public protest. She was succeeded by Harriet Bigelow. Byrd was briefly associated with the Normal College of the City of New York (now Hunter College) but subsequently removed to her parents' farm in Lawrence, Kansas. Nonetheless, she remained active in pedagogical reforms through the 1920s. Byrd was a member of the American Astronomical Society, the Astronomical Society of the Pacific, and the British Astronomical Association.

Jordan D. Marché, II

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C

Cacciatore, Niccolò

Born **Casteltermini near Agrigento, (Sicily, Italy), 26 January 1780**
Died **Palermo, (Sicily, Italy), 28 January 1841**

Niccolò Cacciatore was **Giuseppi Piazzi**'s successor at the Palermo Observatory, although his main scientific contributions were in meteorology. Since his parents wanted him to pursue an ecclesiastical career, Cacciatore studied under the guidance of his uncle, Innocenzo Cacciatore. After taking minor orders in 1796, Niccolò taught Greek in the seminary of Agrigento. The following year he moved to Palermo to study under Giovanni Agostino de Cosmi, who presented Cacciatore to Piazzi, director of the Palermo Astronomical Observatory. Piazzi encouraged the young man to work at the observatory, and in 1800 Cacciatore was appointed as an assistant. In 1817, Cacciatore became director, on Piazzi's recommendation, when Piazzi became general director of the observatories of Naples and Palermo. After the death of Niccolò, his son Gaetano took his place as director.

Niccolò Cacciatore was fellow of the Royal Society of London, member of the Società Italiana delle Scienze (dei XL), and Secretary of the Accademia del Buon Gusto in Palermo. As Piazzi's assistant, he helped the director in the construction of the *meridiana* drawn in the floor of the Palermo Cathedral (1801), in the reform of the Sicilian weight and measures system (1809), in the draft of a geographic map of the Palermo valley (1808–1811), but especially in editing Piazzi's second star catalog (1814). Piazzi, in the foreword to his catalog, lauded Cacciatore's collaboration in making observations and calculations of the star positions. This work made him the prime candidate as Piazzi's successor at the Palermo Observatory, as he auspicated by inserting the name of ROTANEV SUALOCIN (palindrome of NICOLAUS VENATOR, the Latin for NICCOLÒ CACCIATORE) alongside the stars α and β Delphini in the catalog. In this way he designated himself as Piazzi's Dauphin, with Piazzi's approval.

Cacciatore ordered and published the meteorological observations made at the Palermo Observatory from 1791 and acquired and installed several meteorological instruments. He designed a mercury seismoscope and an anemoscope, and thanks to his impulse, the meteorological observations at the observatory became very regular and accurate. Unfortunately, Cacciatore was implicated in some personal controversies, especially with the physicist Domenico Scinà, which dimmed, to an extent, the international prestige of the Palermo Observatory.

Ileana Chinnici

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Cailean MacLabhruinn

❯ **Maclaurin, Colin**

Calandrelli, Giuseppe

Born **Zagarolo near Rome, (Italy), 22 May 1749**
Died **Rome, (Italy), 24 December 1827**

Giuseppe Calandrelli served as the astronomer of the former Jesuit Collegio Romano during the period of the suppression of the Society of Jesus. As such he was Rome's preeminent astronomer in the first decades of the 19th century. His work was traditional positional astronomy, including observations of comets and eclipses and accurate measurements of stellar positions and motions. He was one of the early claimants to the detection of annual stellar parallax, and his work in that area was significant in the Church's eventual removal, by 1820, of restrictions regarding the teaching of Copernicanism.

Calandrelli was the son of Tommaso Calandrelli and Maria Fortini. He received a philosophical and theological education at the Vatican and Albano seminaries leading to the priesthood, but he developed an interest in mathematics and astronomy and studied them deeply on his own. After teaching at the seminary of Magliano Sabina from 1769 until 1773, he returned to the Collegio Romano in 1774, now run by secular clergy after the suppression of the Jesuits, to teach mathematics, physics, and astronomy, during which time he also published some minor mathematical works.

As the astronomy professor, Calandrelli was nominally the director of the Collegio Romano Observatory, which had been created, but not actually constructed, by Pope Clement XIV. It was the "academy" of Cardinal Zelada that gave Calandrelli his first practical astronomical experience, in the cardinal's private observatory, including observations of the 1786 transit of Mercury. Not until 1787 did Zelada order a suitable tower to be constructed at the Collegio Romano and equipped with basic instrumentation, so that Calandrelli was finally in charge of a true Collegio Romano Observatory. Calandrelli's observational career took place in that thin tower visible even today atop the old Collegio Romano building. The observatory was still poorly equipped, but years of toil in relative obscurity ended when Pope Pius VII, in 1804, equipped the observatory with an achromatic telescope and a good clock, soon followed by a Reichenbach transit instrument. The pope also provided funds for the publication of the work of Calandrelli and his colleagues, who included Andrea Conti, Giacomo Ricchebach, and eventually his nephew **Ignazio Calandrelli**. The published works, entitled *Opuscoli astronomici* (Rome, 1803–1824), would eventually fill eight volumes. The published research included the exact determination of the latitude and longitude of the observatory (based in part on work done earlier by **Roger Boscovic**), methods for reduction of observational data, calendrical formulas, observations of comets C/1807 R1 and C/1811 F1 and the solar eclipse of 1804, analysis of ancient Roman astronomical records, meteorological observations, and annual parallax measurements of the star Vega (α Lyra), among others. Calandrelli also served for a time as the president of the Gregorian University during the period of the Napoleonic occupation of Rome. In 1824, when Pope Leo XII reconstituted the Society of Jesus and restored the Collegio Romano to them, Calandrelli voluntarily gave up his post and took his instruments and work to the College of Saint Apollinarius in Rome. Until his death he occupied himself with minor ecclesiastical duties, writing, and planning a new, but never-built, observatory.

Calandrelli's attempts to measure annual stellar parallax put him among a handful of early 19th-century astronomers who were striving after the same goal. His claim to have measured the parallax of Vega was not generally accepted by other European astronomers. (In fact, his result of just over 4″ is about a factor of 30 too large, and therefore undoubtedly spurious.) However, the claim itself was very influential in the debate within the Vatican bureaucracy leading up to the Church's decision to allow publication, in 1820, of an overtly Copernican scientific work, thus effectively ending the prohibition that originated in the trial of **Galileo Galilei**. The advocates of liberalization cited Calandrelli's work on Vega repeatedly as evidence that the annual motion of the Earth was no longer hypothesis but an established fact.

Calandrelli engaged in wide correspondence with many contemporary astronomers, much of which is now lost, and was a member of various institutes and academies. His published works are now rare.

James M. Lattis

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Calandrelli, Ignazio

Born **Rome, (Italy), 22 November 1792**
Died **Rome, Italy, 12 February 1866**

Ignazio Calandrelli was an observational astronomer and observatory director. Calandrelli was the son of Carlo Calandrelli and Margarita Girella and the nephew of **Giuseppe Calandrelli**. At the age of 12, he took religious orders and was admitted to the Gregorian University at the College of Rome. He took a degree in philosophy in 1814 and in the same year became *allievo* (student) at the observatory of the Collegio Romano, where his uncle was director. He concentrated on planetary observations (Uranus, Jupiter, Saturn, and the Great Comet C/1819 N1) but in 1845, due to internal hostilities, he moved to Bologna, where he was named professor of astronomy and director of the local observatory. A few years later Pope Pius IX called Calandrelli back to Rome, and he became director of the Campidoglio Observatory. From 1850 to his death, he concentrated upon comets and eclipses as well as the history of astronomy. Calandrelli was a member of the Lincei Academy and president of the Accademia Tiberina.

Mariafortuna Pietroluongo

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Calcagnini, Celio

Born **Ferrara, (Italy), 1479**
Died **Ferrara, (Italy), 1541**

Italian humanist Celio Calcagnini was a contemporary of **Nicolaus Copernicus**; his written work alludes to a rotating Earth.

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Callippus of Cyzikus

Born **Cyzikus (near Erdek, Turkey), *circa* 370 BCE**
Died **possibly Athens, (Greece), *circa* 300 BCE**

Callippus, a fellow-citizen and follower of **Eudoxus**, is best known for his modifications to the Greek lunar calendar and to Eudoxus' model of the planetary spheres.

Callippus made observations from the Hellespont and moved *circa* 334 BCE to Athens, where he associated with **Aristotle**. To improve the accuracy of Eudoxean planetary models, Callippus added two spheres to the model of the Sun, two to that of the Moon, and one each to the models of Mars, Venus, and Mercury. The two new spheres assigned to the Sun accounted for its unequal motion in longitude, which **Meton** and **Euctemon** had discovered a century earlier but Eudoxus ignored. Callippus assigned 94, 92, 89, and 90 days to the northern spring, summer, autumn, and winter, respectively. (The error in these numbers ranges between 0.08 and 0.44 days.) Presumably, the two new spheres for the Moon performed a similar task. We do not know the exact purpose of the supplementary spheres in the case of Mars, Venus, or Mercury.

Callippus' most significant contribution to astronomy rested in a better adjustment of the lunar calendar used by the Greeks to the solar year. He replaced Meton's 19-year cycle with a 76-year cycle. Meton's scheme provided for the intercalation of 7 months in the course of 19 lunar years and the regular elimination of 1 day from some of the 30-day months. If the rules were followed properly, the cycle would comprise $(19 \times 12) + 7 = 235$ months, of which 110 had 29 days, making a total of 6,940 days. Since 19 tropical years amount to 6,939.6 days, the Metonic calendar errs, on average, by a little more than 30 min year^{-1}. Callippus' scheme of $4 \times 19 = 76$ years intercalates $4 \times 7 = 28$ months, but subtracts 1 day from each of 441 months, and therefore comprises 27,759 days. Since 76 tropical years amount to 27,758.4 days, the Callippean calendar errs, on average, by only 11.3 min year^{-1}, which is the accuracy of the Julian calendar.

Roberto Torretti

Alternate name

Kãllippow

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Campani, Giuseppe

Born **Castel San Felice, (Umbria, Italy), 1635**
Died **Rome, (Italy), 28 July 1715**

Giuseppe Campani was one of Europe's foremost telescope makers and opticians in the 17th century. Born in a village near Spoleto, he came from a peasant family and had no university education. He soon went to Rome with his two brothers, one of whom was a cleric, the other a clockmaker. Campani learned clockmaking, probably studied optics at the Collegio Romano, and became skilful in grinding lenses.

In 1656 Campani, along with his brothers, made a silent night clock, which, when presented to Pope Alexander VII, brought him fame. He then became a full-time lens grinder, a trade carried out for nearly 50 years, constructing telescopes and lenses in Rome. He worked for important individuals all over Europe and for the Royal Observatory in Paris. The Pope and his nephew, Cardinal Flavio Chigi, remained among Campani's most important patrons, but he also won the patronage of Ferdinand II, Grand Duke of Tuscany, and of Cardinal Antonio Barberini, who took the first Campani telescope out of Italy to Paris, where he exhibited it.

In 1664 Campani developed a lens-grinding machine; there is a controversy over whether it could polish lenses without the use of molds. (A number of Campani's molds do survive.) He was able to fashion the best composite eyepieces and lenses, primarily for telescopes but also for microscopes. He also improved telescope tubes by constructing them of wood rather than of cardboard covered with leather. Even if this design was somewhat unwieldy, it proved durable, and wooden telescopes continued in use until the 19th century.

Campani made some significant observations with his own instruments. Between 1664 and 1665, particularly, he observed the moons of Jupiter and the rings of Saturn. His astronomical observations and descriptions of his telescopes are detailed in these papers: *Ragguaglio di due nuove osservazioni, una celeste in ordine alla stella di Saturno, e terrestre l'altra in ordine agl'instrumenti* (Report on two new observations, the one heavenly about Saturn, the other earthly about instruments), published in Rome in 1664 and again in 1665 and *Lettere di G.C. al sig. Giovanni Domenico Cassini intorno alle ombre delle stelle Medicee nel volto di Giove, ed altri nuovi fenomeni celesti scoperti co' suoi occhiali* (G.C.'s letters to Mr. Giovanni Domenico Cassini about Medicean stars' shadows on the face of Jupiter, and other new heavenly phenomena discovered with his own telescopes), published in Rome in 1666.

A bitter rivalry grew up between Campani and telescope maker **Eustachio Divini**, who also worked in Rome. From 1662 to 1665 this rivalry became a hot dispute, and many "comparisons" were made between the instruments of the two. The first public comparison took place at the end of October 1663 in the garden of Mattia de' Medici, in the presence of some famous astronomers like **Giovanni Cassini**. The contest ended in a draw, since they acknowledged that Divini's telescope had a bigger magnification but Campani's had a better focusing. Many other comparisons were made in the following months, but they virtually ended in July 1665, when Campani's 50-span-long telescope was unanimously judged as the best ever constructed.

Early on, Cassini became convinced that Campani's telescopes were better than Divini's. Because of Cassini, Campani's instruments equipped the Royal Observatory in Paris and all of Cassini's discoveries were made with Campani's telescopes.

Marco Murara

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Campanus of Novara

Born **Novara, (Italy), first quarter of 13th century**
Died **Viterbo, (Italy), 1296**

His contemporaries, like **Roger Bacon**, considered Campanus as one of the greatest mathematicians of his times. The date of his birth can be tentatively fixed between 1210 and 1230 because the first entry in some tables ascribed to him is 1232 and many of his works are dated between 1255 and 1260. Many documents confirm Campanus' birthplace: Novara in northern Italy, 40 km from Milan. Sometimes he is called Johannes (John), but this first name seems to have been introduced only in the 16th century.

We do not know anything of Campanus's life until 1263 when he was chaplain of Cardinal Ottobono Fieschi, later Pope Adrian V. In 1264, Campanus was chaplain to Pope Urban IV, and he remained a member of the papal court for 30 years until his death in 1296. There Campanus served as mathematician, astronomer, astrologer, and physician, and he met other outstanding intellectuals such as the translator **William of Moerbeke**, Witelo (author of the first treatise on optics), and Simon of Genoa (author of a famous medical dictionary).

At the time of his death Campanus was a rich man, owner of many prebends in Italy, France, Spain, and England, and many buildings in Viterbo, the place of the papal court at the end of the 13th century.

Campanus's fame is mainly related to a Latin edition of Euclid's *Elements* in 15 books, which was the standard Euclid for 200 years and the first printed version in 1482, and to the *Theorica Planetarum*. Probably a rearrangement of some Arabic work, the main purpose of this work is to describe the construction of an instrument for finding the position of the heavenly bodies, generally called an equatorium. Campanus gives not only a description of the Ptolemaic solar, lunar, and planetary models on which the instrument is based, but also the dimension of each model, with all its constituent parts, both relative to itself and absolutely. The *Theorica* proved to be an early exemplar of the way speculation and instrumentation worked together. It had great success; it is preserved in more than 60 manuscripts, many with illustrations and movable parts. Abbreviated versions were also prepared by later astronomers such as **John of Lignères** in the 14th century and **John of Gmunden** in the 15th century.

Other astronomical works ascribed to Campanus are as follows:

- the adaptation of the Toledan tables to the meridian of his own town, Novara;
- a treatise on the Computus, a typical form of literature on the calendar, of which he prepared two versions, a long (*maius*) and a short (*abbreviatus*);
- a *Tractatus sphaera*, an introduction to spherical astronomy;
- a summary of the contents of **Ptolemy**'s *Almagest*, the *Almagestum parvum*;
- a treatise on the quadrant, where he demonstrated more interest in the theoretical part than in the construction and practical usage of this instrument.

Campanus was also famous as an astrologer. He wrote a treatise on this subject, and a famous method of the division of astrological houses to cast horoscopes was ascribed to him.

Giancarlo Truffa

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Campbell, Leon

Born **Cambridge, Massachusetts, USA, 20 January 1881**
Died **Cambridge, Massachusetts, USA, 10 May 1951**

Hired at the age of 18 by Harvard College Observatory director **Edward Pickering** as a dome assistant, Leon Campbell enjoyed a lifetime of astronomy in and around his home city. In 1911 Pickering sent Campbell to Arequipa, Peru, to direct the Harvard Station there. After his return to Cambridge in 1915, Campbell coordinated the work of Harvard's volunteer variable star observers and also became intimately involved with the fledgling American Association of Variable Star Observers [AAVSO]. In 1930 **Harlow Shapley** appointed Campbell to the Edward Charles Pickering Memorial Professorship, which included full-time coordination of the work of the AAVSO.

Thomas R. Williams

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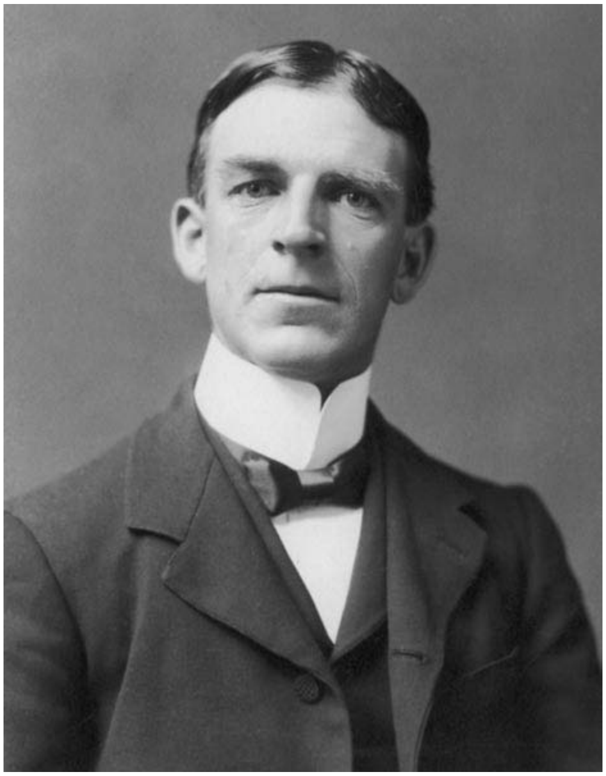
Campbell, William Wallace

Born **Hancock County, Ohio, USA, 11 April 1862**
Died **San Francisco, California, USA, 14 June 1938**

William Campbell (Wallace to his friends), a spectroscopist and Lick Observatory director, designed spectrographs, measured a large number of radial velocities, and led a number of eclipse expeditions, one of which decisively confirmed the **Albert Einstein** deflection of starlight.

After a childhood of poverty and hard work on an Ohio farm, Campbell earned enough by teaching school to enter the University of Michigan as a civil engineering student. In his third year he discovered **Simon Newcomb**'s *Popular Astronomy*, and it changed his life. He devoured the book in two days and two nights and decided to become an astronomer. Professor **John Schaeberle** taught him to observe and to calculate comet orbits, activities that continued to command his interest for several years. After graduation Campbell taught mathematics for 2 years at the University of Colorado, returning to the University of Michigan to replace his teacher when Schaeberle joined the initial Lick Observatory staff in 1888. During the summer of 1890, Campbell learned spectroscopy by assisting **James Keeler** as a volunteer observer at Lick.



Campbell's talent and willingness to work hard were noted by Lick Observatory director **Edward Holden**. When Keeler resigned to become director of the Alleghany Observatory in 1891, Campbell became a permanent member of the Lick Observatory staff. In 1892 he married Elizabeth Ballard Thompson, an English major who had taken an astronomy course from him at Colorado.

Working visually, Keeler had already achieved more precise measurements of wavelengths than the aging **William Huggins** (whose wife **Margaret Huggins** did most of the actual observing by this time) or **Joseph Norman Lockyer** in England, but it was becoming clear that photography would be the method of the future. Campbell designed a superior spectrograph that would be rigid and temperature-controlled. Then, while Holden persuaded San Francisco financier Darius O. Mills to fund construction of the new instrument, Campbell attached a camera to Keeler's old spectroscope on the 36-in. Clark refractor, at that time the world's largest refractor.

Campbell quickly became the most successful spectroscopist in the world. By 1896, when the Mills instrument came into service, neither Keeler in cloudy Pennsylvania nor Huggins, Lockyer, or **Hermann Vogel** in Europe could compete with the much larger telescope, superior spectrograph, and excellent skies of Mount Hamilton. No diplomat, Campbell was quick to point out the errors of others; he won few friends in London or Potsdam. During the 1890s, Campbell made important studies of the spectra of nebulae, Wolf–Rayet stars, comets, and the bright Nova Aurigae. He vigorously and correctly disputed Huggins's claim that there is a significant amount of water vapor in the atmosphere of Mars. Later, in 1909, Campbell took a 16-in. heliostat and spectrograph up 4,750 m to the top of Mount Whitney to compare the spectra of the Moon and Mars, setting a low limit for water vapor content in the Martian atmosphere.

When Holden was forced to resign in 1898 and Keeler was appointed Lick Observatory director, the latter, who was a diplomat, gave himself a job no one else wanted and left spectroscopy to Campbell. When Keeler died suddenly 2 years later, 12 of the world's leading astronomers recommended that Campbell succeed him. That same year Newcomb also nominated Campbell for the first Nobel Prize in Physics. On 1 January 1901, Campbell became the third director of the Lick Observatory. He would retain the title for 30 years.

Following the examples of other major observatory directors like **George Airy** and **Edward Pickering**, Campbell the creative scientist became, in the words of Donald Osterbrock, John Gustafson, and Shiloh Unruh, a "factory manager." One of the most hardworking and hard-driving scientist–managers of all time, Campbell organized the Lick Observatory staff and channeled most of the observatory's resources into his program of measuring radial velocities. By 1907, his efficient spectrograph could obtain usable spectrograms of sixth-magnitude stars with an exposure of 2.5 hours under average atmospheric conditions. Several more hours of plate measurement and reduction were required for each star.

By 1914, the radial velocity survey was almost complete to stars of the ninth magnitude. Campbell's primary goal was to determine the motion of the Sun with respect to the average motion of the stars. The resulting value of the solar apex was published in 1925 and provided a basis for later elaboration of the structure of our Galaxy. Campbell's program also led to the discovery of a great many spectroscopic binary systems, as a result of which it gradually became clear that multiple-star systems are quite common.

In his first year as director, Campbell persuaded Mills to donate an additional $24,000 to obtain radial velocities of southern stars as well. The sum was sufficient to build a 36-in. Cassegrain reflector with a permanently mounted spectrograph, ship it to Chile, set up an observatory, and pay the two-man staff for 2 years. Campbell himself was seriously injured when the mounting fell on him during testing, so his assistant, **William Wright**, led the first expedition. The Mills southern station of the Lick Observatory was a great success, so Mills and later his son extended its operation for many more years.

The consolidated Northern and Southern Hemisphere surveys yielded radial velocities for 2,771 stars, published in catalog form in 1928. By combining the data from Campbell's radial velocity catalog with proper motions derived by **Benjamin Boss**, **Frederick Seares** was able to compute statistical parallaxes for 1,200 stars grouped by apparent magnitude.

Campbell's other great specialty was solar eclipse expeditions. He traveled to India (1898), the state of Georgia (1900), Spain (1905), the South Pacific (1908), Russia (1914), Washington state (1918), and Australia (1922). He measured the wavelength of the green coronal radiation and used a moving plateholder to obtain a photographic record of the changing spectrum near the beginning and end of totality. The 1922 eclipse expedition confirmed Einstein's prediction that starlight would be deflected by the Sun's gravity. Many scientists had accepted the results of **Arthur Eddington** and **Frank Dyson** at the 1919 eclipse, but **Robert Trumpler**'s measurements of the Australia plates made by him and Campbell 3 years later had much smaller uncertainties.

On six of the expeditions, Elizabeth Campbell was in charge of the commissary and managed most of the logistics. "Bess" was considered a great humanizing influence on a man who was often seen as inflexible and domineering.

When the Campbells returned from Australia, they were met at the dock by a delegation from the University of California regents insisting that he accept the presidency of the university. By this time he was 60 and a world-renowned scientist with five medals. He did not want the job of president, but he took it when the trustees met his conditions: He would retain the position of director of Lick Observatory and the regents would promise not to interfere in internal matters of the university. **Robert Aitken** would be associate director and run the day-to-day affairs on Mount Hamilton, but he would have to consult Campbell on all major decisions, and the Campbells would keep the director's house (by now a rather palatial one) for occasional visits and entertaining.

As a university regent said when Campbell retired from the presidency and the observatory directorship in 1930, "With a hand always gentle but always firm and never shirking, President Campbell ruled the University wisely and well." Faculty members who chafed under his authoritarian style conceded later that he had been the most effective president they had seen.

Even in retirement the Campbells kept the director's house on Mount Hamilton, but they were soon off to Washington, where Campbell served as president of the National Academy of Sciences from 1931 to 1935. These years were not happy ones for the septuagenarian astronomer, who was extremely conservative and frequently unhappy with President Franklin D. Roosevelt.

Campbell lived his last 3 years in San Francisco. Suffering from aphasia, blind in one eye and losing the sight of the other, and unwilling to become a burden to his family, he committed suicide.

Campbell's attitudes about women in the field of astronomy have been questioned by historians who have noted, for example, that he refused to endorse **Annie Cannon**'s participation in the First International Astronomical Union General Assembly as a representative of the United States. On the other hand, Campbell was the first major observatory director to allow women to undertake observational research. He directed the research of the first two woman Ph.D. astronomers who graduated from the University of California/Lick Observatory (Phoebe Waterman [Haas] and Anna Estelle Glancey).

Campbell was awarded the Lalande Medal in 1903 and the Janssen Medal in 1910 by the French Academy of Sciences, the Henry Draper Medal of the National Academy of Sciences in 1906, the Gold Medal of the Royal Astronomical Society in 1906, and the Catherine Wolfe Bruce Medal of the Astronomical Society of the

Pacific in 1915. He served as president of the International Astronomical Union, 1922–1925; the American Association for the Advancement of Science, 1915; the American Astronomical Society, 1922–1925; and the Astronomical Society of the Pacific, 1895 and 1910. Campbell held numerous other offices in these and other societies.

Campbell's papers are in the Mary Lea Shane archives of the Lick Observatory, University of California, Santa Cruz.

Joseph S. Tenn

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Camus, Charles-Étienne-Louis

Born **Crécy-en-Brie near Paris, France, 25 August 1699**
Died **Paris, France, 4 May 1768**

As a member of the Académie royale des sciences, Charles-Étienne-Louis Camus took an active part in the scientific life of 18th-century Paris and is particularly known for his participation in the astronomical and geodesic program to define the shape of the Earth. He also contributed to clockmaking and mechanics.

Camus was the son of a surgeon. From an early age, he showed a special gift for mathematics, while being clever with his hands, making and repairing iron or wood objects. He persuaded his parents to let him study in the Collège de Navarre in Paris. After leaving the college, Camus continued mathematical studies on his own, later with the aid of Pierre Varignon, a member of the academy. He also began studies in geometry, civil and military architecture, mechanics, and astronomy.

In 1727 Camus presented a dissertation to the academy on ships' masts; this work was appreciated by the academy, which decided to include it among the works to be published. Camus also was rewarded with half the prize money. On 5 August 1727 the academy elected him an *adjoint-mécanicien* member. In the following year, Camus submitted a memoir in favor of the idea of *vis viva*, which was then being debated. Until 1730, the academy records refer to him as the abbé Camus. He must have left the priesthood about that time, as he married Marie-Anne-Marguerite Fournier in 1733. They had four daughters, only the eldest of whom reached adulthood.

In 1730 Camus was appointed as a professor of geometry in the Royal Academy of Architecture, being named its secretary 3 years later. In 1733 Camus presented a memoir on toothed wheels and the gears, which was a generalization of some work previously presented by **Philippe de La Hire**. He also showed talent in dealing with clock and watch-making questions. In 1733 Camus and **Alexis-Claude Clairaut** were both elected as associate members of the Académie royale des sciences.

During these years, the French scientific establishment debated the shape of the Earth and planets. As previous measurements by **Giovanni Cassini** disagreed with the Newtonian theory, the academy ordered two expeditions to measure the length of a degree along the meridian, one to Peru (1735) and one to Lapland (1736–1737). Camus participated in the latter, which was led by **Pierre de Maupertuis.** The abbé **Réginald Outhier**'s account of the expedition, *Journal d'un voyage au Nord, en 1736 & 1737*, appeared in Paris in 1744. It recounts Camus' efforts as a clockmaker, mechanic, and engineer, all of which were invaluable to the success of the expedition into these distant and inhospitable areas. Camus erected the expedition's lodgings, assembled and regulated its measuring devices, and manufactured clocks for various experiments.

As the Lapland results were equivocal, further expeditions were arranged. Camus joined the Lapland team to remeasure the length of the arc of the meridian in the vicinity of Amiens made by **Jean Picard** in 1669/1670. With other astronomers, **Pierre Bouguer**, **Cesar Cassini de Thury**, **and Alexandre Pingré**, Camus was involved in similar measurements between Montlhéry and Juvisy to produce the Carte de France. A new expedition, with these same astronomers, was undertaken in the Amiens area in 1756.

In 1745 Camus undertook, along with Jean Hellot, some metrological work. From that time Camus was heavily involved in the routine work of the academy, examining memoirs and machines submitted to it, attending meetings, undertaking evaluation missions, and participating in different projects.

Camus was designated as a pensioner-geometer member in the academy in 1741, as *sous-directeur* in 1749 and 1760, and *directeur* in 1750 and again in 1761. In 1745 he was appointed by the academy to be an examiner in the royal engineering schools, a position that led him to write a mathematics textbook. The first three parts, on arithmetic, geometry, and mechanics, were published; the drafts concerning hydraulics were found in his home after his death. This textbook, even with some defects, was used widely in French engineering schools. Camus was elected at the Royal Astronomical Society in 1765.

Camus caught a bad flu during the winter of 1766 as he traveled to Metz to organize an examination; he was recovering when the news of his daughter's death late in 1767 came to him. Camus was reported to be an upright man, apolitical, plain in discussion, although sometimes quick to retort. Although not a scientist of the first rank, Camus was an important participant in the work to establish the figure of the Earth.

Monique Gros

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Cannon, Annie Jump

Born **Dover, Delaware, USA, 11 December 1863**
Died **Cambridge, Massachusetts, USA, 13 April 1941**

Annie Jump Cannon, the "Dean of Women Astronomers," American astronomical computer, classified spectra of a quarter of a million stars on a system partially of her own devising.

Cannon's father, Wilson Lee Cannon, was a shipbuilder and lieutenant governor of the state of Delaware. Her mother, Mary (Jump) Cannon, was interested in astronomy and had taken a course in astronomy at the Friends' School. Annie recollected a childhood marked by many hours with her mother studying the constellations. She attended Wellesley College from 1880 to 1884 and distinguished herself in physics and astronomy. Professor **Sarah Whiting**, a pioneer woman in science, encouraged Cannon to pursue spectroscopy.

It is believed that Cannon's deafness resulted from exposure to the harsh winter cold during her first year at Wellesley. She learned to use a hearing aid and to speechread to deal with her progressive loss of hearing. Her deafness became very severe by middle age. At astronomical conventions, she preferred one-to-one conversations. Fellow scientists noted that she was almost completely deaf without the aid, and some ventured that this fostered her great power of concentration.

In 1894, 1 year after her mother died, Cannon returned to Wellesley to assist with X-ray experimentation. Following the advice of **Edward Pickering**, the director of the Harvard College Observatory, she then pursued studies at Radcliffe, and he appointed her to the observatory staff in 1896. She would spend her entire career there.

During her early years at the observatory, Cannon sharpened her skills in studying variable stars. In 1911, she became curator of astronomical photographs. One of the most extensive efforts to classify the stars was Pickering's Henry Draper Catalog, which provides the positions, magnitudes, and spectra of 225,300 stars. That invaluable reference for astronomers covers the heavens from pole to pole for all stars brighter than the eighth magnitude, as well as many fainter stars, and provides data on distances, distributions, and motions. Scientists investigating the colors, temperatures, sizes, and compositions of stars frequently refer to the Henry Draper Catalog for its spectral information. Development of the catalog was a colossal challenge – nearly a quarter of a million stars had to be classified.

After the equipment was readied in both hemispheres, Pickering himself chose Cannon as the principal investigator for the project.

In this capacity, she not only identified, recorded, and indexed the data on the stars but also supervised the publication of all nine volumes. Cannon personally examined every single one of these spectra.

When Cannon began her classification of the stars, she revised the symbols used for the spectral types. Originally, **Williamina Fleming** had used letters of the alphabet, and **Antonia Maury** employed Roman numerals. Cannon reordered the classes in more specific and subtle terms of decreasing surface temperature. The Draper classification scheme she devised was introduced in her *Catalogue of the Spectra of 1122 Stars,* and it was adopted internationally. Only slight modifications have been made to the system since.

Cannon was the first woman to receive the Henry Draper Medal for "notable investigations in astronomical physics." Her contributions in the field of spectroscopy were unsurpassed in quantity. Probably no other single observer in the history of science gathered so great a mass of data on a single system. Cannon believed patience, not genius, was responsible for her success. Her pioneering work has been validated for its thoroughness in the Henry Draper Catalog.

Cannon examined photographs of the stars near the South Celestial Pole for years, discovering many variable stars and novae. Throughout her career, she classified one-third of a million stars, and discovered more than 300 variable stars, 5 novae, and many stars with peculiar spectra.

Cannon won many honors for her work. **William Campbell** (1941) called her the "world's most notable woman astronomer." In 1925, she received an honorary Doctor of Science degree from Oxford University, the first woman recipient in its 600-year history. Other honorary degrees were conferred upon her from the University of Groningen in the Netherlands, University of Delaware, Oglethorpe University, and Mount Holyoke College. Wellesley presented her with the degree of Doctor of Laws in 1925. Cannon was an honorary member of the Royal Astronomical Society in England, one of only six people ever to receive such a status since the Society's establishment in 1820. In 1938, she was appointed William Cranch Bond Astronomer for her distinguished service at the Harvard College Observatory.

The Ellen Richards Research Prize was awarded to Cannon in 1932. She used the money to endow the Annie J. Cannon prize of the American Astronomical Society [AAS] (administered by the American Association of University Women for a number of years but since 2004 being administered once again by the AAS). It is to be given every other year (annually, 1988–2004) to an outstanding woman astronomer. The first recipient was **Cecilia Payne-Gaposchkin**.

As is too often the case, the honors received by Cannon came primarily from outside the Harvard College Observatory. Although she encountered the same discrimination that challenged other women of her time, Cannon was also a *deaf* woman during America's brief flirtation with Social Darwinism. Thus, she faced additional barriers to her advancement and professional recognition. Her status as a "defective," openly discussed in the correspondence of several leading eugenicists in the early 1920s, seems to have prevented her from being nominated as a member of the National Academy of Sciences. Pickering himself did everything in his power to gain her recognition. In addition to crediting her work in his reports, he wrote to President Lowell in 1911, encouraging him to appoint her Curator of Astronomical Photographs (replacing Fleming) and to give her a corporation appointment. Lowell did not give Cannon the appointment. **Harlow Shapley**, Pickering's successor at the observatory, also felt strongly that Cannon deserved greater recognition at Harvard. To grant her further visibility, Shapley encouraged other universities to award Cannon honorary degrees.

It was not until 1938, 3 years before her death, that Cannon received the William Cranch Bond Astronomer Award and a corporation appointment from Harvard. A Moon crater is named in her honor. Cannon was, according to **Dorrit Hoffleit**, the happiest person she ever met.

Harry G. Lang

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Capella, Martianus (Felix) Mineus [Minneius, Minneus]

Flourished **Carthage, (Tunisia), 5th century**

Martianus Capella was an author of late Antiquity about whose life little is known, and all conjectures about dates in which he lived have arisen from possible clues within his one known work. As a consequence, scholars disagree as to whether he worked in the early or latter end of the century. Some sources state that Capella was born in Madaura, a town 150 miles southwest of Carthage, and the home of Apuleius (of "Golden Ass" fame), but W. H. Stahl argues that there is no evidence for this. Capella tends to use legal terms and language, but Stahl states that a Roman legal expert suggests that a layman could have used such terms. In short, there is no consensus on Capella's dates of birth, death, or his occupation.

Capella compiled what is often referred to as the "Satiricon" (or "Satyricon"), a kind of encyclopedia, which was widely admired, used, and commented on in the Middle Ages. Specifically, its title was *De Nuptiis Philologiae et Mercurii* (Concerning the marriage of Mercury and Philology). The work as a whole is a mixture of prose and verse, with a touch of self-deprecation and mockery of learning that is in a style established by Menippus of Gadara, a philosopher of the "Cynic" group.

De Nuptiis involves an allegory about the apotheosis of learning and is a mild sort of satire, more bemused in tone (with occasional ribaldry and slapstick) than biting or sarcastic. Modern scholars, especially those of the 19th and early 20th century, have deplored the often-ponderous Latin prose (with better reviews for the poetry), but students and scholars in the Middle Ages found it engaging if not charming.

The work organizes the liberal arts into seven divisions: the *trivium* (grammar, logic, dialectic, and rhetoric) and the *quadrivium* (arithmetic, geometry, astronomy, and music). These subjects are introduced as special guests at the wedding of the maiden Philology (scholarly learning) with Mercury (eloquence). Among the arts, "Geometry" is described as a distinguished-looking woman bearing the tools of her trade, and "Astronomy" is portrayed as a beautiful and essentially timeless maiden whose discourse summarizes much of the practical astronomical knowledge of Antiquity. She reveals that she hid among the priests in Egypt for 40,000 years, and in Greece, "hidden by the philosopher's cloak" lest her knowledge be divulged and profaned. Of course, in such an august assemblage of the gods as at the wedding, such knowledge can be safely revealed.

"Geometry" describes the use of ratios of daylight to nighttime hours to delineate latitudes. She notes that the polar regions are areas where there is no end to daylight during the summer and no sunrise during winter, and that the northern and southern polar regions are each other's antipodes. "She" goes on to say, "Pytheas of Massilia reported that he found such a condition on the isle of Thule. Those discrepancies of the seasons, unless I am mistaken, compel us to admit that the Earth is round."

"Astronomy" reveals the inequality of the seasons, and attributes this effect to the displacement of the Earth from the center of the Sun's orbit. According to Stahl and R. Johnson, the direct source of "her" information is probably **Geminus**, and ultimately **Hipparchus**. "She" speaks of the relative sizes of the Moon, Sun, and Earth, referring to observational determinations involving timings of the disks to rise (with clepsydras) compared to the time interval of a solar or lunar day, and describes in detail solar and lunar eclipses and planetary phenomena.

In general, comments about the placings and risings/settings of the stars are compiled from the writings of Aratus, Geminus, **Hyginus**, and **Manilius**, for the most part and possibly Marcus Terentius Varro, author of a work entitled "Menippean Satires." Planetary orbit data seem to be derived mainly from **Theon of Smyrna** and **Pliny** according to Stahl and B. S. Eastwood.

Most scholars consider Capella exclusively a compiler of other people's data, and bereft of any original observations or calculations. As noted by Stahl and Johnson, **Otto Neugebauer** concluded that no observations by Capella were involved in the details he provided about rising times and lengths of daylight and darkness ($14\frac{1}{6}$ h and $9\frac{5}{6}$ h, respectively); these numbers would seem to be appropriate for the environs of Carthage (not far from the present city of Tunis, across the Lake of Tunis), between the latitudes of Alexandria and Rhodes, but may represent only an attempt at interpolation.

The work has many curious errors; we mention only one here. Capella cites **Eratosthenes**' value for the circumference of the Earth: 252,000 stadia in "Geometry," but an incorrect 406,010 stadia in "Astronomy," a number similar to, but given to higher precision, than what appears in **Aristotle**. Of course, the texts that we have must have been recopied several times, and passages are frequently noted to be corrupt.

Capella's compilation earned him the respect of perhaps 50 or 60 generations, reaching down to **Nicolaus Copernicus** and even into the present. For example, G. Sarton placed him among a group of writers who mention **Heraclides**, a forerunner of **Aristarchus.** The Heraclidean perception of the Solar System had Mercury and Venus "rotate" around the Sun, which with the Moon and other planets, "rotated" about the Earth. Capella's "Astronomy" states the view plainly: "The center of their orbits is set in the Sun." It is a natural conclusion, given the maximum elongations of those interior planets, if not generally espoused in antiquity.

Eugene F. Milone

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Capra, Baldassarre

Born **Milan, (Italy), 1580**
Died **Milan, (Italy), 8 May 1626**

Baldassarre Capra was involved in controversies with **Galileo Galilei**. Capra was born of noble parents. He studied medicine, astrology, and mathematics at Padua University. Both he and his father, Count Marco Aurelio Capra, became friends of Galilei, but this friendship soon ended. In October 1604, Capra observed a new star in Ophiucus or Serpens – it was the nova that inspired **Johannes Kepler**'s *De Stella nova in pede serpentari*, 1606 – and

Galilei discussed the subject in three lectures without ever mentioning Capra. Capra's response was to publish *Consideratione astronomica* … (Padua, 1605) in which he claimed credit for the discovery. Galilei did not reply, at least in writing, but a second more serious episode happened. In 1607, Capra published *Usus et fabrica circini* … (Use and construction of geometrical dividers) at Padua, a book that was largely copied from Galilei's *Operazioni del compasso geometrico e militare* (Use of geometrical and military dividers; Padua, 1606). This time Galilei reported Capra's behavior and plagiarism to the *Riformatori* (the Reformers, the board of academic censors of Venice). The verdict was favorable to Galilei, and the *Riformatori* ordered all copies of Capra's book to be destroyed.

Ennio Badolati

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Cardano, Girolamo

Born **Pavia, (Italy), 24 September 1501**
Died **Rome, (Italy), 21 September 1576**

Italian physician, and man-about-Europe, Girolamo Cardano cannot be called a Copernican. Still, he did offer the interesting argument that, perhaps, only the Moon revolves about the Earth – as its "effects" are different from those of the other planets.

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Carlini, Francesco

Born **Milan, (Italy), 7 January 1783**
Died **Crodo (Verbania, Piedmont), Italy, 29 August 1862**

Francesco Carlini was director of the Brera Astronomical Observatory in Milan from 1832 to his death, contributing both to theoretical and practical astronomy. Carlini was born in Milan, son of an employee at the Brera library, which was housed in the same building as the observatory. As a young boy he was already performing calculations for the astronomers. **Barnaba Oriani**, a Milanese astronomer, introduced him to astronomy. Oriani was famous for his contributions to the first determination of a circular orbit for Uranus. For more than 40 years Oriani directed the scientific work of the Brera astronomers and maintained relations with most European astronomers. Carlini was admitted to the observatory as a student when he was just 16, becoming "supernumerary" astronomer in 1804, astronomer (replacing Oriani) in 1816, and director in 1832, succeeding Angelo de Cesaris. When he died, he had spent a total of 63 years at Brera.

As astronomer, Carlini's first appointed task was to compile *Effemeridi*, an almanac, which Bernhard Lindenau and Johann von Bohnenberger considered to be the most accurate available until **Johann Encke**'s *Berliner Astronomisches Jahrbuch* and the British *Nautical Almanac*. In 1809, Carlini wrote a widely appreciated paper, *Tavole della nutazione solare in ascensione retta ed in declinazione* (Tables of solar nutation in right ascension and in declination). **Friedrich Bessel**, in a letter to Oriani from Königsberg on 27 November 1812, praised Carlini's solar tables, which he found "very convenient." Fifty years later, **Giovanni Schiaparelli**, commemorating Carlini, claimed that the new method devised by Carlini brought about a veritable revolution in the format used for the tables of heavenly motions.

Carlini published many memoirs on the subject of asteroids, leading to the fundamental theoretical work, *Researches on the Convergence of the Series that is Useful for the Solution of Kepler's Problem*. The discovery of asteroids had revealed new theoretical problems for astronomers because they had very large eccentricities. The series then used converged very slowly, and it was not clear where it was appropriate to truncate it. A study of the limit to which the series tended was necessary, and Carlini found a very elegant solution. As shown by Fröman and Fröman (1985), Carlini's method is the direct predecessor of the WKB method, introduced in 1926 by Wentzel, Kramers, and Brillouin, in order to find, approximately, the eigenfunctions and eigenvalues of **Erwin Schrödinger**'s equation.

Carlini's memoir was greatly appreciated not only by astronomers but also by mathematicians. Carl Gustav Jacob Jacobi in 1849 published an article in which he claimed that, to his knowledge, this was the most difficult problem ever tackled in astronomy. Jacobi translated Carlini's memoir into German and published it, at the same time correcting a small error Carlini had made in his calculations. In 1852, Carlini built a machine able to calculate the solutions to Kepler's problem.

In 1811, following a suggestion of **Pierre de Laplace**, the Brera astronomers devised a lunar research program involving astronomers from several Italian states. Because of many difficulties, only Carlini and **Giovanni Plana** from Turin were able to carry out the program. For this work, in 1820, Carlini and Plana wrote a paper that won a prize of the Académie des sciences in Paris, promoted by Laplace, to whoever succeeded in constructing lunar tables based solely on the law of universal gravity. The prize was shared with **Marie Damoiseau**. But if on the one hand Laplace praised Carlini and Plana for their work, he also criticized a few important points. A bitter dispute ensued in *Connaissance des temps* and in the *Correspondance Astronomique, Géographique, Hydrographique et Statistique* of **János von Zach**. In the end, Laplace recognized that the two Italian astronomers were more accurate than him. Carlini and Plana planned to publish a complete theory of the Moon in three volumes. But, despite reciprocal esteem, the collaboration did not work. Carlini contributed only to the first volume of the theory, which, however, was fully published by Plana alone under his own name.

Carlini had a lifelong involvement with important geodetic operations. Worthy of note is the measurement of the meridian arc between Andrate and Mondovì, across the Alps, measured first by Giovanni Battista Beccaria, whose measurements were controversial and had some inconsistencies. Carlini and Plana, once again together, found the origin of the anomalies in the deviation of the plumb line due to the presence of high mountains. And in 1827, Carlini carried out astronomical measurements for the determination of the mean parallel between the Atlantic and the Adriatic Sea.

In 1832, Carlini married Gabriella Sabatelli. He was a member of important scientific societies, including the Royal Astronomical Society of London, the Göttingen Society of Sciences, and the French Institute. At his death, he left part of his estate to the observatory as well as his manuscripts, which now are kept in the Archives of the Brera Astronomical Observatory.

Pasquale Tucci

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Carpenter, James

Born **Greenwich, England, 1840**
Died **Lewisham, (London), England, 17 October 1899**

Greenwich Observatory assistant James Carpenter cowrote, with **James Nasmyth,** *The Moon: Considered as a Planet, a World, and a Satellite* (1874). To support their interpretations of lunar features, the two authors prepared physical models and then photographed them under different illuminations.

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Carrington, Richard Christopher

Born **London, England, 26 May 1826**
Died **Churt, Surrey, England, 27 November 1875**

In addition to his unique contributions to knowledge about the axis and rotation of the Sun, Richard Carrington produced a valuable catalog of the positions of circumpolar stars. The son of a wealthy Brentford, Middlesex, brewer, Carrington was, along with **Johannes Hevel** and **William Lassell**, one of several notable amateur astronomers whose astronomical careers were founded on brewing fortunes. Educated at Cambridge University, he served for 3 years as an assistant to Reverend Temple Chevalier at Durham University Observatory.

However, his father's money made him "an unfettered man," as he put it, and in 1853 Carrington set up a superior observatory of his own, at Redhill, Surrey, south of London. He commissioned a transit circle with a 5-in. object glass and a 4½-in. equatorial refractor from the instrument makers Troughton and Simms. Carrington also hired an assistant, George Harvey Simmonds, whose salary was comparable to that received by junior assistants at the Greenwich Royal Observatory at the time.

As a result of his work at Durham, Carrington was aware that the catalogs of **Friedrich Bessel** and **Friedrich Argelander** were notoriously less accurate as they approached the North Celestial Pole. He decided that rectifying that deficiency in existing catalogs should be his first contribution to practical astronomy. Using the transit circle, Carrington began sweeping stars in zones at declinations of +81° or more for purposes of producing a catalog. The work eventually included 3,735 circumpolar stars. It was published at the expense of the British Admiralty and won Carrington the Gold Medal of the Royal Astronomical Society in 1859.

Even this ambitious project was insufficient to exhaust Carrington's energies, and while busily measuring stellar positions at night, he began a rigorous program of solar observations by day. Fascinated by the discovery of the sunspot cycle, which had been announced by the German amateur **Samuel Schwabe**, he attempted to extend Schwabe's observations. Using the 4½-in. equatorial, Carrington projected a 11-in. image of the Sun on to a white screen. By sighting on a perpendicular pair of gold wires set at a 45° angle to the Sun's motion across the sky and allowing the Sun to drift through the field, Carrington recorded the transit times of the solar limbs and sunspots on each of the wires, on a day-to-day basis. Extended from November 1853 to March 1861, these observations allowed him to precisely fix the position of the Sun's axis of rotation and to determine the period of the Sun's rotation as a function of heliographic latitude.

A sunspot minimum occurred in 1855. By 1858, Carrington had grasped that the distribution of sunspots at different latitudes changed over the course of the sunspot cycle. Following a sunspot minimum, sunspots began to appear on each side of the Equator between 20° and 40° of latitude; they then moved steadily closer and closer to the Equator as the cycle progressed until they disappeared at the next sunspot minimum. Then a new crop of spots associated with the next cycle began to appear in midlatitudes. In 1859, Carrington recognized that rotation periods of spots near the Equator were consistently shorter than those near the Poles. In attempting to extend Carrington's results, the German astronomer **Friedrich Spörer** of the Potsdam Observatory later confirmed the variations in latitude of sunspot zones during the solar cycle. The result is sometimes known as Spörer's law, although Carrington was clearly the first to recognize it.

Despite Carrington's exhaustive scrutiny of the Sun over a period of several years, he never once suspected the existence of an intra-Mercurial planet, although **Urbain Le Verrier**'s hypothesis and the supposed observation of the French amateur **Edmond Lescarbault** were coming into prominence at the time. Carrington did, however, make an observation that was highly singular. On the morning of 1 September 1859, just after he finished his routine observations, he noted two intensely bright patches in a large sunspot group located in the Sun's Northern Hemisphere:

> My first impression was that by some chance a ray of light had penetrated a hole in the screen attached to the object-glass …. I … noted down the time by the chronometer, and seeing the outburst to be very rapidly on the increase, and being somewhat flurried by the surprise, I hastily ran to call some one to witness the exhibition with me, and on returning within 60 seconds, was mortified to find that it was already much changed and enfeebled (Carrington, 1859).

In all, the brilliant phase had lasted for not more than 5 min.

At the same moment as Carrington's observation, another amateur, R. Hodgson, using a 6-in. refractor at Highgate, was independently monitoring the Sun. He too recorded "a very brilliant star of light … dazzling [even] to the protected eye, illuminating the upper edges of the adjacent spots and streaks." Carrington inferred "the phenomenon took place … altogether above and over the great [sunspot] group in which it was seen projected."

Within minutes of Carrington and Hodgson's observations, instruments at the Kew Observatory detected a disturbance of the Earth's magnetic field, while brilliant auroral displays were seen on succeeding nights. Although Carrington himself suggested the flare might have been associated with the disturbance of terrestrial magnetism, he hastened to add that "one swallow does not make a summer." It is now well known that flares can produce disturbances of terrestrial magnetism, interrupt shortwave communications, and produce auroral displays.

In 1865, Carrington moved his residence-observatory to Churt, Surrey. His years there were unproductive. Astronomically, he burned out early, and by the time he was in his midthirties, his best work was behind him. In part this was because his traditional methods of monitoring the Sun were already being superseded – as early as March 1858, **Warren de la Rue** at the Kew Observatory, using a shuttered refractor to make exposures short enough to prevent overexposure of the wet-collodion plates then in use, began obtaining photographic images of sunspots. De la Rue's daily program of solar photography, commenced at Kew, was later transferred to Greenwich Observatory.

Unfortunately, Carrington had other preoccupations. He was the opposite of Swithin Saint-Cleve, Thomas Hardy's budding astronomer whose interest was financed by a well-to-do patroness. Instead, the well-to-do Carrington fell hopelessly in love with a beauty, Rosa Helen Rodway (*neé* Jeffries), who proved to be an illiterate fortune hunter with a past. He resolved to marry her, and marry her he did. Unfortunately, she already had a former lover and common-law husband, William Rodway. An ex–trooper in the Dragoons and recently employed in looking after the horses in a circus, Rodway followed the Carringtons to Redhill. Rosa accounted for his unwanted attentions by telling Carrington he was her brother. Eventually, Rodway seems to have been made to feel less than welcome at the Carringtons. In 1872, after a drunken visit to the house at Churt, he stabbed Rosa. He was arrested and sent to jail, but information about Rosa's sordid past came out at the trial. Three years later, Rosa was found dead in bed. An autopsy determined that she died of asphyxiation, perhaps related to an overdose of chloral hydrate, which she took for her insomnia. Carrington was criticized by the coroner for failure to provide appropriate nursing care. Carrington himself died of a cerebral hemorrhage only 3 weeks later.

Carrington's career is one of the more tragic careers in the history of astronomy. But he will always be remembered for his important work on sunspots, and for being the first to see a flare on the Sun.

William Sheehan

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Cassegrain, Laurent

Born **near Chartres, (Eure-et-Loir), France, *circa* 1629**
Died **Chaudon, (Eure-et-Loir), France, 31 August 1693**

The name of Cassegrain is associated with the optical configuration of the so called Cassegrain telescope, the type most widely used in the world. However, the man who gave his name to this reflecting telescope had not been clearly identified before 1997. Laurent Cassegrain was the son of Mathurin Cassegrain, a grocer and haberdasher in the town of Chartres, and Jehanne Marquet. Although Cassegrain's birth certificate has not yet been found, we know that Laurent had at least five brothers and sisters, who were born and baptized in Chartres between 1631 and 1646. According to the age indicated in his death certificate, Laurent was born between 1628 and 1630, at a time when the plague was raging in France. While a number of Cassegrain's relatives were surgeons in Chartres, nothing is known of the education of Laurent, who is not mentioned in local records before 1654. He is then described as a Roman Catholic priest and a teacher of Latin, Greek, and religious duties at the Collège-Pocquet, then the only high school in Chartres.

Like most of the scholars of his time, Cassegrain's wide interest included physics, especially acoustics, optics, and mechanics. He corresponded on these subjects with his friend Claude Estienne (1640–1723), a canon of the Cathedral of Chartres who was also "Prieur De Bercé." It is thanks to two letters, which he sent to Estienne in 1672, that the name of Cassegrain has become famous. Part of one of these letters was published in the issue dated 2 May 1672 of the *Mémoires et Conférences pour les Arts et les sciences*. In the 1672–1674 period, this publication acted from time to time as a substitute for the *Journal des Sçavans*, where the works of the French Académie des sciences were reported. This letter, which Cassegrain sent from Chartres, gave the results of his calculations of the proportions to be given to the Chevalier Morland's megaphones (called *trompettes à parler de loin*). This text undoubtedly proves that its author was well versed in science. The second letter was not published; Estienne merely refers to it in the issue dated 25 April 1672. Estienne did not always sign his regular letters to the *Journal des Sçavans*, and this is the only one he signed "M. De Bercé." As he was also a correspondent of **Christiaan Huygens**, it is most likely that 17th-century scholars knew who Bercé actually was. Estienne said that he could not help to react upon the paper on the reflecting telescope, which **Isaac Newton** had just presented to the Royal Society of London. This paper was published in the *Journal des Sçavans* dated 29 February 1672, and it is worth mentioning that the English version was published later, in the *Philosophical Transactions* of 25 March. Newton's telescope was composed of a parabolic concave primary mirror and a small plane one at 45°, which reflected the rays through the tube on to an eyepiece situated outside the tube, near its entrance. Estienne said how surprised he had been by that description because about 3 months earlier he had received a letter written by M. Cassegrain, where the author described a reflecting telescope that Estienne considered much more ingenious.

This telescope was composed of a large parabolic concave primary mirror with a hole in its center and a small hyperbolic secondary mirror, which reflected the rays back to the eyepiece through the hole, just behind the main mirror. Neither the drawing nor the accompanying text gave the precise shapes of the mirrors, which were obvious for any reader. Newton promptly replied in the *Philosophical Transactions* on 20 May 1672. He gave first the translation of Estienne's paper, before he developed a number of criticisms. He ended asking Cassegrain through Estienne to build a real telescope before arguing about the achievements of others. Huygens gave Newton his strong support in the *Journal des Sçavans* (13 June 1672), accusing Cassegrain of having badly copied the telescope described by **James Gregory** in his *Optica Promota* (1663). Gregory's telescope was actually different since its secondary mirror was an elliptical concave one, which cut the rays reflected by the primary behind the prime focus. It was thus longer than Cassegrain's. The dispute ended quickly because it was well-known that it was practically impossible to make aspherical mirrors: Newton's concave one was actually spherical and of relatively poor quality, and the situation was, of course, worse for convex ones. It is, however, quite surprising that the name of **Marin Mersenne**, well-known to scholars of the time, had not been cited. In 1651, Mersenne had given the descriptions of the three types of telescopes in his posthumous book *L'Optique et la Catoptrique*.

Despite the existence of the large "Cassegrain" (focal length of 7.8 m) built by the Benedictine monk Dom Noël in Paris in 1771, and despite the attempts in 1779 by Jesse Ramsden to grind and polish aspherical convex surfaces, nearly two centuries were to pass before the Cassegrain telescope came to be widely adopted, thanks to **Jean-Bernard-Léon Foucault**, who developed the method of making silvered glass mirrors and the test for them, which bears his name.

Laurent Cassegrain moved from Chartres with his mother in 1685. He became the *curé*, of Chaudon, a small village near Nogent-le-Roi (about 30 km north of Chartres), where he died. Although the priests were usually buried inside their parish church at that time, Cassegrain's will was to be buried in the churchyard.

Various factors contributed to the wide use of a name whose owner was such an obscure figure. The confrontation with scientists like Newton and Huygens has always been considered as the main one. An obvious consequence of it was that the basic drawing published by Estienne in 1672 has become a well-known historical image. The imaging qualities of the Cassegrain form compared with those of the Gregorian were emphasized in 1779 by Ramsden, who gave much publicity to the former. Ramsden said that the aberrations introduced by the two mirrors added up in the Gregory form, while they canceled each other out in the Cassegrain one. This is true but only for the center of the field and only if both mirrors of the telescope are spherical. The telephoto effect is much bigger in the Cassegrain form, although the difference was not so important in the 1670s, when both types of telescope were much shorter than the commonly used refracting instruments. Cassegrain was undoubtedly the first to describe the observing position called soon the Cassegrain focus. This expression, which is now used for any form of telescope where the observation is made just behind the main mirror, will definitely ensure that Cassegrain's name will never be forgotten.

Françoise Launay

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Cassini I

➜ **Cassini, Giovanni Domenico [Jean–Dominique]**

Cassini II

➜ **Cassini, Jacques**

Cassini III

➋ **Cassini de Thury, César-François**

Cassini IV

➋ **Cassini, Jean-Dominique**

Cassini de Thury, César-François

Born **Thury near Clermont, (Oise), France, 17 June 1714**
Died **Paris, France, 4 September 1784**

Cassini de Thury was best known as a cartographer and was a key figure in the controversy over the shape of the Earth. He was the son of **Jacques Cassini** (Cassini II) and Suzanne-François Charpentier de Charmois. César-François was educated at the family home in the Paris Observatory by his granduncle **Giacomo Maraldi**. Elected to membership of the Académie des sciences in 1735, he succeeded his father as director of the Paris Observatory.

Cassini began his career just as the controversy over the shape of the Earth reached its peak, with the Cartesian concept seemingly in the ascendancy. At this stage he was loyal to the family's Cartesian leanings, that the Earth is elongated along the line of its poles. In 1733/1734, he, with others, assisted his father to determine the arc of the great circle perpendicular to the meridian of Paris, a survey necessary for the mapping of France. These measurements seemed to confirm the Cartesian view. But to settle the matter, the Académie sent out geodetic expeditions to Lapland (1736/1737) and to Peru (1735–1744). The results did not support Cartesian position. Although his father refused to renounce his long-held belief, Cassini III eventually accepted the view that the Earth is an oblate spheroid.

The experience he gained in geodetic theory and practice enabled Cassini in 1733 to persuade the Académie des sciences of the importance of such operations, and in 1735/1736 he completed the guidelines of his most important work, a new map of France. With geodetic data acquired between 1733 and 1740 as a basis, he drew up a map in 18 sheets on the scale of 1:870,000 (*circa* 1746), and later a more detailed map in 182 sheets on a scale of 1:86,400.

Richard Baum

Alternate name

Cassini III

Selected Reference

Hahn, Roger (1971). *The Anatomy of a Scientific Institution: The Paris Academy of Sciences, 1666–1803*. Berkeley: University of California Press.

Cassini, Giovanni Domenico [Jean–Dominique]

Born **Perinaldo near Imperia, (Liguria, Italy), 8 June 1625**
Died **Paris, France, 14 September 1712**

Giovanni (or Gian) Cassini was the first in a dynasty of astronomers prominent in Prerevolutionary France. A skillful observer, but very conservative in theoretical matters, he did not totally accept the Copernican doctrine and vigorously opposed Newtonian gravitational theory. His best work was observational, not theoretical.

Cassini was the son of Jacopo Cassini, of Tuscany, and Julia Crovesi, but was raised by a maternal uncle. He was educated at Vallebone, the Jesuit College at Genoa, and the abbey of San Fructuoso. As a boy, Gian showed great intellectual curiosity and expressed interest in poetry, mathematics, and astronomy.

Paradoxically, Cassini's career began as the result of a brief flirtation with astrology that brought him to the attention of the Marquis Cornelio Malvasia, a rich astronomer and senator of Bologna who produced ephemerides for astrological purposes. Cassini accepted his invitation to work in Malvasia's observatory at Panzano, near Bologna. Here Cassini studied under the astronomer **Giovanni Riccioli**, then completing his great treatise, the *Almagestum novum* (1651), and the physicist **Francesco Grimaldi**, later distinguished for his discovery of diffraction.

In 1650, the senate of Bologna appointed Cassini professor of astronomy at the university, where he wrote a treatise on comet C/1652 Y1 in which he expressed his anti-Copernican views. He also believed that the Moon has an atmosphere and that comets are located beyond Saturn, arising as the result of emanations from the Earth and planets. Later comparison with other observations obliged him to reject the latter hypothesis, and thereafter he considered comets analogous to planets but traveling in paths of greater eccentricity.

One of Cassini's first instruments at Bologna was a large sundial of his own design, mounted on top of the Church of San Petronio and substituted for one made unusable by modifications to the building (1653). With it he made observations of the apparent motion of the Sun, the obliquity of the ecliptic, and the exact positions of the solstices and equinoxes, data that formed the basis of new tables of the Sun he published in 1662. From other observations he also formulated the first major theory of atmospheric refraction.

Using long-focal-length telescopes of excellent definition constructed by the Roman lens makers **Giuseppe Campani** and **Eustachio Divini**, Cassini, starting in 1664, made a series of observations of the planetary surfaces that led to important discoveries. He determined the rotation periods of Mars and Jupiter and obtained values very close to the presently accepted values. His Venus results were very ambiguous. He also reported on the polar flattening of Jupiter and accurately described its bands and spots.

Cassini successfully developed tables of the movements of the satellites of Jupiter and in 1668 published *Ephemerides merides Bononienses mediceorem siderum*. These were used for decades by navigators and astronomers until Cassini published more precise tables in 1693. **Ole Römer** employed them in 1675 to demonstrate the finite nature of the speed of light.

Cassini was by now preoccupied with technical matters on behalf of the Bolognese authorities; in 1663 he became superintendent of fortifications and in 1665 inspector of Perugia. However, his tables of the satellites of Jupiter and his growing number of planetary discoveries attracted the interest of the French who, having recently founded the Académie royale des sciences, were enhancing its prestige by recruiting to its ranks foreign scholars and scientists of distinction. **Christiaan Huygens** had been elected in 1667, and membership was now offered to Cassini. He accepted, and it was then suggested that he come to Paris for a limited period. The terms offered were highly attractive. After diplomatic discussions, the Bologna senate and Pope Clement IX authorized acceptance, but insisted that the appointment was temporary. On 25 February 1669 Cassini set out for Paris. It was in essence the end of his Italian career; he never returned permanently to Italy and in 1673 became a naturalized Frenchman.

The following year, Cassini married Geneviève de Laistre, daughter of the lieutenant general of the Comté of Clermont, whose dowry included the château of Thury in the Oise. They had two sons. The younger, **Jacques Cassini**, became an astronomer and geodesist and succeeded his father (who became blind in 1710) in the supervision and direction of the Paris Observatory.

Gian Cassini failed in his attempt to persuade Louis XIV and his architect Claude Perrault to modify the structure of the Paris Observatory so as to make it a practical observing site. Yet, soon after he arrived in Paris in 1669, Cassini continued the observational series begun in Italy, using lenses by Campani and Divini, and some lenses of French manufacture.

Cassini found the Saturnian moons, Iapetus (1671), Rhea (1672), and Tethys and Dione (both on the same night, 21 March 1684). Variations in the brightness of Iapetus suggested to him that the satellite always turned the same face toward Saturn. Although he abandoned this hypothesis in 1705, a century later **William Herschel** considered it entirely valid.

Cassini observed a band on the globe of the planet and in 1675 observed the division in Saturn's ring system that now bears his name. He described the system as being composed of swarms of tiny particles moving in two concentric rings of different densities.

Between 1671 and 1679 Cassini observed the Moon and drew up an atlas of sketches from which he formed a large map of its surface features. This he presented to the Académie des sciences (1679).

With Niccolo Fatio he made the earliest continuous observations of the zodiacal light, a phenomenon Cassini considered to be of cosmic origin (1683). During the Mars opposition of 1672, Cassini planned simultaneous observations of the planet from Paris (by **Jean Picard** and himself) and Cayenne (by **Jean Richer**) to determine that planet's parallax. The result, which Cassini assumed to be 9.5″ for the Sun, was sufficiently in error that a reasonably accurate estimation of the mean Earth–Sun distance was impossible. However, it was an improvement over earlier estimates.

In 1685 Cassini tried out a "parallactic machine," in effect an equatorial clockwork drive whereby the telescopic object was tracked by gradually shifting the ocular support. He claimed this greatly aided his observations.

In the late 17th century, a controversy arose over the form and dimensions of the Earth. In 1669 Picard had measured an arc of the meridian with some accuracy, on the widely held assumption that the Earth is a sphere. But all was thrown into doubt when Richer reported that the length of a pendulum with a frequency of once a second was smaller at Cayenne (near the Earth's Equator) than at Paris. Richer attributed this to a flattening of the Earth. Huygens and **Isaac Newton** had arrived at the same conclusion but by different methods. Cassini disagreed. He believed in the sphericity of the globe and suggested temperature differences as the cause of Richter's observation. To resolve the issue, Cassini proposed a triangulation of the meridian between the northern and southern frontiers of France. The result led him to propose that the Earth was a prolate spheroid, a viewed favored by the Cartesians. This theory was defended at first by Cassini's son, and then his grandson, but finally rejected by his great grandson.

Judgments on Cassini's contributions are various. **Jean Delambre** charged him with having derived his best ideas from his predecessors and predisposing French astronomy in an authoritarian and retrograde manner. Whatever the truth, he was a gifted observer and indisputably his many discoveries outweigh his failings in theory.

Richard Baum

Alternate name

Cassini I

Selected Reference

Taton, René (1971). "Cassini, Gian Domenico (Jean-Dominique) (Cassini I)." In *Dictionary of Scientific Biography*, edited by Charles Coulston Gillispie, Vol. 3, pp. 100–104. New York: Charles Scribner's Sons.

Cassini, Jacques

Born **Paris, France, 18 February 1677**
Died **Thury near Clermont, (Oise), France, 15 April 1756**

Jacques Cassini, who was mainly an observationalist, was a fervent Cartesian who fought hard to reconcile the facts of observation with the theory of vortices. He was a lukewarm Copernican and never admitted Newtonian gravitation. His main areas of interest were the tides, the planets and their satellites, and the observation and theory of comets. His literary output was vast, but he is chiefly known for his *Élémens d'Astronomie* (Paris, 1740).

Cassini was the son of **Giovanni Cassini** and Geneviève de Laistre. After a period of study at home in the Paris Observatory, Jacques entered the Collège Mazarin. He soon turned to astronomy and was admitted as a student to the Académie royale des sciences (1694).

Cassini accompanied his father on a journey through Italy in 1695, making numerous scientific observations, taking part in geodetic work, and helping to restore the meridian of the Church of San Petronio in Bologna. He then journeyed to the Low Countries, and England, taking various measurements of a geodetic and astronomical nature. In England he made the acquaintance of **John Flamsteed**, **Edmond Halley,** and **Isaac Newton**, and was admitted to the Royal Society.

In 1706, Cassini was designated *maître ordinaire* of the *chambre des comptes* despite a modest legal background. He succeeded his father as supervisor of the Paris Observatory when the latter's health began to fail (before 1710).

In 1700/1701, Cassini took part in his father's expedition to extend the meridian of Paris as far as the southern border of France. He criticized **Willibrord Snel**'s 1617 measurements of the arc of meridian, and presented a new method of longitude determination based on occultations of stars and planets by the Moon.

In 1713, Cassini joined the controversy between the Cartesians and the Newtonians over the figure of the Earth, by adopting the prolate spheroid hypothesis. Cassini based his view on previous measurements of arcs of meridian, the results of which suggested the degrees of a terrestrial meridian lessen from the Equator to the Pole. In 1718, he participated in measuring an arc of meridian from Dunkirk to the Pyrenees, and relying on the results of this project in 1722 published *De la grandeur et de la figure de la terre*, wherein he affirmed his support for the Cartesian view. Although **Jean de Mairan** sought to reconcile the apparent disagreement between theory and observation, the Newtonians sharply attacked Cassini's position and those of his supporters. In his defense, Cassini, backed by his sons and others of like mind, in 1733/1734 organized an operation to determine the perpendicular to the meridian of Paris, from Saint Malo to Strasbourg. This seemed to bring a measure of satisfaction to the Cartesians, and confirmed their belief about an egg-shaped Earth. The Newtonians disputed this conclusion and persuaded the Académie to mount expeditions to Peru (1735–1744) and Lapland (1736–1737) to measure arcs of latitude at more widely separated points on the globe. Following the return of the Lapland party with results that supported the Newtonian position, an unconvinced Cassini abandoned the field to his son, **César Cassini de Thury**, bothering only to respond to an attack from **Anders Celsius** in 1738. Two years later, perhaps realizing the futility of further opposition to Newtonianism, he gave up on serious scientific pursuits, and during his last few years assisted Cassini de Thury in preparing the foundations for a new map of France.

Richard Baum

Alternate name

Cassini II

Selected Reference

Grant, Robert (1852). *History of Physical Astronomy, from the Earliest Ages to the Middle of the Nineteenth Century*. London: Henry G. Bohn. (Reprinted in 1966. New York: Johnson Reprint Corp.)

Cassini, Jean-Dominique

Born **Paris, France, 30 June 1748**
Died **Thury near Clermont, Oise, France, 18 October 1845**

Last of the Cassini dynasty at the Paris Observatory, J.-D. Cassini was an administrator, a geodesist, and a cartographer. He was the son of **César Cassini de Thury**. Educated at the Collège du Plessis, Paris, and the Oratorian Collège at Juilly, Jean-Dominique studied under the physicist J. A. Nollet, the mathematician C. Mauduit, and the astronomers **Giacomo Maraldi** and **Jean Chappe d'Auteroche**. He was elected *adjoint* by the Académie des sciences on 23 July 1770, becoming *associé* in 1785. Cassini was the editor of Chappe d'Auteroche's posthumous *Voyage en Californie pour l'observation du passage de Vénus sur le disque du soleil, le 3 juin 1769* (Paris, 1772), and formally succeeded his father as director of the Paris Observatory in 1784. He was married to Claude-Marie-Louise de la Myre-Mory for 18 years. Her death in 1791 left him with five young children: Cécile, Angélique, Aline, Alexis, and Alexandre Henri Gabriel, who became a jurist and a botanist, and with whom the French line of the Cassini family died out.

Cassini IV was put in charge of further tests of the marine chronometer of Pierre le Roy while on an Atlantic cruise in 1768. But his plan to modernize and reorganize the Paris Observatory during the last years of the *ancien régime*, which received royal assent from Louis XVI in 1784, was only partially realized when the Revolution began. His main preoccupation in later years was completion of the great map of France, a task undertaken by his father, and in 1787 he was involved, along with **Adrien Legendre** and **Pierre Méchain**, in geodetic operations joining the Greenwich and Paris meridians.

As a monarchist, Cassini was hostile to the Revolution, and from March 1793 opposed reforms that the new administration wanted to impose upon the observatory. After much bitter dispute, he resigned on 6 September 1793. His leaving some weeks later brought the Cassini reign to a close after 120 years. On 14 February 1794, he was denounced by a revolutionary committee and imprisoned. On his release in August of that year he retired to the family château at Thury. Subsequently, he declined nomination to the Bureau des longitudes (1795) and to the astronomy section of the new Institut National in January of the following year. Cassini accepted election to the experimental physics (1798) and astronomy sections (1799) of the institute, but when refused renomination to the Bureau des longitudes, withdrew from scientific work and devoted the rest of his life to local politics.

Richard Baum

Alternate name

Cassini IV

Selected Reference

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Cassiodorus, Flavius Magnus Aurelius

Born **(Sicily, Italy),** ***circa*** **485**
Died **Scyllacium (Squillace, Calabria, Italy),** ***circa*** **585**

Encyclopedist Cassiodorus was born into a landed and politically prominent southern Italian family in the decade after the ascent of the Ostrogoth King Odovacer in 476. He advanced through numerous public offices under King Theodoric and his successors, becoming prefect of Italy in 533, an office he retained until his retirement in 537/538. During that time Cassiodorus worked to unite the Germanic and Italian elements in Italy. During his public career he associated with many of the leading intellectual and political figures of the day, including **Boëthius** and **Dionysius Exiguus**, possibly being taught by the latter and succeeding the former as *magister officiorum* in 523. He also planned unsuccessfully to establish a Christian school of learning at Rome (*circa* 535). Cassiodorus later (550) spent time in Constantinople assisting Pope Vigilius with ecclesiastical and doctrinal matters, and then spent his remaining years in retirement at the monastery of Vivarium, which he founded on his family estate at Scyllacium.

The historical and political writings of Cassiodorus (*Chronica*, *Variae*, and a lost history of the Goths) represent invaluable documentation for governmental matters in late Roman times and for Ostrogothic rule in Italy. His numerous other works include tracts on religious matters (*De anima, Expositio psalmorum*) and on guidelines for the copying of texts (*De orthographia*), one of the chief activities undertaken at Vivarium.

Two works of Cassiodorus contain astronomical and calendrical material. The first is the *Institutiones divinarum et humanarum lectionum* (Divine and human readings), an encyclopedia for Christian and secular education in two books (*circa* 562–565). The chapter entitled *De astronomia* (2.7) is a general and primarily practical description of astronomy in four sections that only very superficially treat the subject matter. It begins with the conclusion that there is an immutable law governing the heavens but that divine intervention, evidenced by Biblical passages, may supersede the natural order of things. The second section outlines basic astronomical precepts as a series of definitions: of the celestial cardinal points; of relative sizes of the Sun, Moon, and Earth; and of eclipses. Cassiodorus's material on planetary movements is specifically attributed to the Greeks, and he also cites Varro's (incorrect) etymology for the Latin *stella*. The following section specifically recommends the works of **Ptolemy** for an understanding of the zones corresponding to celestial and terrestrial latitudinal divisions and of the importance of these in accurate timekeeping. The final section addresses the proper Christian approach to the study of astronomy: that the association of astronomy with belief in Fate must be rejected and that humans ought not aspire to the levels of knowledge beyond what is in the Scriptures.

A much shorter work, the *Computus paschalis*, is a tract written to explain the intricacies of the Christian calendar, including the various methods of determining the dates of Easter and of the days of the week. Its primary importance is that it was the first work to incorporate the calendar revisions developed by Dionysius Exiguus, whom Cassiodorus knew and respected. However, although the work has generally been thought to have been composed in 562 by Cassiodorus at Vivarium, its actual authorship remains unverified. Moreover, in recent years the work itself has been identified as a verbatim copy of Dionysius's *Argumenta Paschalia* with some revisions and additions to update it to 562. The work's true significance is in what it reveals about the Alexandrian calendrical model.

John M. McMahon

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Castelli, Benedetto (Antonio)

Born **Brescia, (Italy), 1578**
Died **Rome, (Italy), 19 April 1643**

Benedetto Castelli was one of **Galileo Galilei**'s principal collaborators, an important academic physicist, and a contributor to the diffusion of Copernicanism in the 17th century. He entered the Benedictine order at Brescia in 1575, taking the name Benedetto by which he is now universally known. Before 1604, moving to the monastery at Santa Giusta near Padua, he came into contact with and studied under Galilei from 1604 to sometime in 1607, a period that marked the turning point of his intellectual life, after which he relocated to Cava for a few years. In 1610, likely during the summer of that year when he was back in Brescia, Castelli suggested using the phases of Venus as a test for the Copernican solar system in his correspondence with Galilei; the phases were observed by Galilei in October. They became a central verifying observation described in Galilei's 1632 work, *Dialogue on the Two Chief World Systems*.

By 1611 Castelli was in Florence, the city to which Galilei had just moved after being appointed mathematician to the Medici court. In 1612, again in correspondence, he suggested to Galilei a method for observing sunspots using real image projection. This is described in the second of Galilei's *Letters on Sunspots* (1613) in which Castelli is praised as an empirical scientist and described as a monk from Monte Cassino. At Galilei's urging in the court, he was appointed professor of mathematics at the University of Pisa, the same position Galilei had occupied some 20 years before, in 1613; he was confirmed for life in 1624. During this period, Castelli met and mentored **Bonaventura Cavalieri**, a talented Milanese student whose contributions to the founding of calculus are well known. He resigned his post in 1626 after being called to Rome in 1623 by Pope Urban VIII to serve as papal expert on hydraulics. Water supply was a major engineering concern in the 17th century, and Rome and the papal states were certainly not without serious need of attention. He also tutored the pope's nephew, Tadeo Barberini. Castelli was later appointed professor of mathematics at the University of Rome, retaining this position until his death. His most illustrious pupils there were **Evangelista Torricelli** and **Alfonso Borelli**, both of whom would later make important contributions to mathematics and physics.

Castelli's principal work was in hydraulics – not astronomy or mechanics – a field to which he was introduced by Galilei after he had taken his post in Pisa. This included studies of the *bilancetta* (hydraulic balance), a device first described by Galilei in the 1580s, and Archimedian hydrostatics. His publication *Della misura della acque corranti*, on the measurement of flow rates in rivers, was a pioneering work in hydrodynamic engineering. His studies also included the new field of radiant heat, which was the subject of a lengthy exchange of letters with Galilei on the effects of color and composition of bodies in their reaction to radiant heat (1637–1638), which, it should be recalled, required considerable ingenuity to measure quantitatively with the thermal apparatus of the day. In correspondence in 1634 regarding the illumination of the Earth and Moon by the Sun, Castelli proffered the conclusion that the brightness of a body is proportional to its surface area and inversely proportional to the square of its distance. He advocated the use of aperture stops to improve the images of refracting telescopes, a technique later extended by **Johannes Hevel,** and also investigated physiological optics and the camera obscura.

Many of Castelli's most important contributions are known only from secondary references. He produced few papers or treatises during his lifetime, none specifically dealing with astronomy or fundamental mathematics, but he was broadly influential among his contemporaries through his correspondence, and internationally known. His place in the history of science is dominated by a single event, the correspondence in 1613 with Galilei regarding the comparative roles of science (empiricism and theory) and biblical literalism in theology. The letter was subsequently expanded and published by Galilei as the *Letter to the Grand Dutchess Christina* and served as one of the central points of contention during Galilei's trial before the Inquisition. But Castelli stands as a superb example of a philosophical person of the "seicento" in whose mind and work the Galilean concepts of empiricism took firm hold.

Steven N. Shore

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Cauchy, Augustin-Louis

Born **Paris, France, 21 August 1789**
Died **Sceaux near Paris, France, 23 May 1857**

Augustin-Louis Cauchy was one of the outstanding mathematicians of the 19th century. His contributions to astronomy are recognized even today through contemporary problems bearing his name, such as the Cauchy problem in general relativity and Cauchy horizons for black holes.

Augustin-Louis was the eldest of six children (four boys, two girls), born just 1 month after the storm of the Bastille, to Louis-François Cauchy (1760–1848) and Marie-Madeline Desestre (1767–1839). The Revolution interrupted the middle-class lifestyle of Louis-François, principal *commis* to the *Lieutenant-Général de Police* of Paris. Fearing what he perceived as a dangerous situation for himself and his family, Louis-François fled to his country estate at Arcueil with his wife and his two sons, Augustin-Louis and Alexandre-Laurent, in 1794. Ever solicitous of his children's education, he began teaching them at Arcueil and continued that task for several years after the political situation stabilized.

On the advice of **Joseph Lagrange**, a friend of the Cauchy family, Augustin-Louis was enrolled in the École Centrale du Panthéon, Paris, in the fall of 1802. Three years later he entered the École Polytechnique and in 1807 was admitted to the École des ponts et chaussées, where the major portion of instructional time was spent on fieldwork involving highways and bridges. After completing his studies there, Cauchy was assigned to Cherbourg in 1810 to work on the construction of the Port Napoléon. Two of the four books he took with him to Cherbourg were **Pierre de Laplace**'s *Mécanique céleste* and Lagrange's *Théorie des fonctions analytiques*.

Because of ill health, Cauchy left Cherbourg and returned to Paris in 1812. During his sick leave he continued working on mathematical research begun at Cherbourg. Although he returned to work as an engineer in Paris, Cauchy had academic ambitions, and the years 1812–1815 found him establishing his mathematical reputation. After failing to be appointed to a position several times, due to political infighting in academia, Cauchy finally received an appointment to the École Polytechnique in 1815. Besides this position, Cauchy's academic experience included positions at the Collège de France and the Faculté des sciences. His most notable nonacademic position was at the Bureau des longitudes.

With his appointment to the École Polytechnique, Cauchy had a somewhat secure place in life, so his father decided it was time for him to marry, choosing for him Aloïse de Bure, daughter of bookseller Marie-Jacques de Bure. They married at the Church of Saint-Suplice in Paris on 4 April 1818. The couple had two daughters, Marie-Françoise-Alicia born in 1819 and Marie-Mathilde born in 1823.

What was ostensibly a trip to restore his physical and emotional health, after the July Revolution of 1830, developed into a self-imposed exile for Cauchy. This was in part due to his refusal to swear allegiance to the new regime, which resulted in a loss of his academic positions in France. During this exile, Cauchy spent some time in Turin and in 1832 was appointed to a chair in mathematical physics at the University of Turin by King Carlo Alberto. The following year Cauchy moved to Prague to tutor Charles X's grandson, the Duke of Bordeaux. Cauchy returned to France in 1838.

For 10 years following his return, Cauchy's intransigence was the cause of many lost appointments. For example, in 1839, he was appointed to the Bureau des longitudes, but his refusal to swear an oath of allegiance to the new government made this appointment short-lived. Finally, in 1848, with the establishment of the Second Republic, the act requiring the oath of allegiance was repealed. In October 1848, **Urbain le Verrier**, who held the chair in mathematical astronomy at the University of Paris – a chair that had been specifically created for him—transferred to a chair in physical astronomy. Indications are that he did this to create a position for Cauchy, and, indeed, Cauchy was appointed to the chair in mathematical astronomy in March 1849.

In April and May of 1857, Cauchy presented papers to the Académie des sciences concerning a new method for determining star positions based on the use of coefficient regulators, an artifice he developed from analysis resulting in greater accuracy for calculating coefficients of series expansions. After these presentations, on the advice of his physician, Cauchy left Paris for his country home in Sceaux, suffering from what he called "great rheumatism." For the first few days he seemed to improve, but his condition worsened, and Cauchy died.

The preeminence of Cauchy's work was recognized through various awards albeit some were politically motivated. These include appointment to the Académie des sciences (1816), the *Légion d'Honneur* (1819), foreign membership in the Royal Society of London (1832), and the bestowed title of Baron by Charles X (1837). Cauchy also was granted membership in the Academy of Sciences of Berlin, the Academy of Saint Petersburg, and the Royal Society of Prague among others. In addition, several lunar features are named for Cauchy: Crater Cauchy, Rima Cauchy, and Rupes Cauchy.

Cauchy, along with **Carl Gauss**, was one of the last universal mathematicians in the sense that his research permeated all the then extant branches of mathematics. Cauchy's two most significant contributions to mathematics were his seminal work in the theory of functions of a complex variable and providing calculus with a rigorous, firm, theoretical foundation. Although less well-known, the fundamental results he obtained in celestial mechanics were also significant.

The origin of Cauchy's research in celestial mechanics can be traced back to a paper presented to the Turin Academy of Sciences on 11 October 1831. In the introduction to this paper Cauchy pointed out the need for strengthening the mathematical underpinnings of astronomy. The "bible" for astronomers during this period was Laplace's *Méchanique céleste*. Laplace based his calculation methods on series expansions but did not address any questions about convergence – questions that were fundamental to Cauchy's approach to series.

Cauchy published over 40 papers on celestial mechanics from 1831 until 1857. In general, these works placed astronomy on a rigorous analytic foundation, similar to his efforts in mathematics. In particular, Cauchy was successful in developing methods that simplified the tedious computations involved in celestial mechanics, especially simplifying the computation of error estimates and the series expansion for the perturbation function.

Perhaps Cauchy's most noteworthy contribution to astronomy was an 1845 report on Le Verrier's study of the motion of the minor planet (2) Pallas. This study involved interpolation formulas that required lengthy calculations. The simplifications produced by Cauchy encouraged Le Verrier to investigate the unexplained perturbations of Uranus. Ultimately, this led to Le Verrier's discovery of the planet Neptune, first by calculation and then by observation in September 1846.

John J. Saccoman and *Bert G. Wachsmuth*

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Cavalieri, Bonaventura (Francesco)

Born **Milan, (Italy), *circa* 1590–1600**
Died **Bologna, (Italy), 27 December 1647**

Bonaventura Cavalieri was a professor of astronomy at Bologna and one of the great mathematicians of the 17th century, credited for initial steps toward integral calculus. Cavalieri's date of birth and his Christian name (probably Francesco) are uncertain. Bonaventura was his father's name, which Cavalieri adopted in 1615 when he took the minor orders with the Jesuati (not Jesuits). In 1616 Cavalieri was transferred to the monastery in Pisa, where he met **Benedetto Castelli** – a mathematics lecturer in Pisa and friend of **Galileo Galilei** – who took him under his wing. Castelli introduced him to geometry and Euclid, **Archimedes**, and **Apollonius**. In 1620 Cavalieri was called to Milan to teach theology at the monastery of San Girolamo, where he continued his mathematical studies. Because of difficulties with superiors, he applied unsuccessfully for the mathematics chair at Bologna – vacant with **Giovanni Magini**'s death. Cavalieri asked Galilei for support, having met him earlier in Tuscany. In 1621 he was ordained a deacon by Cardinal Federico Borromeo, who esteemed him and recommended him to Galilei for his extraordinary mathematical abilities.

During his stay in Milan, Cavalieri developed his initial ideas on the theory of indivisibles, and in 1622 he wrote his first observations, sending a copy to Galilei. This marked the beginning of their correspondence. (One hundred and twelve of Cavalieri's letters and two extant letters of Galilei's are in the *Works* of Galilei.)

Between 1623 and 1625, Cavalieri was prior of San Pietro in Lodi, near Milan. Following a short stay in Florence, he then went to Rome, attempting to obtain the chair of mathematics at Pisa and Rome. From 1626 to 1629, Cavalieri was prior of the monastery of San Benedetto in Parma. In the autumn of 1629, he was struck by an illness of the lower limbs, which would afflict him for the rest of his life. This period was nonetheless very profitable: he continued his studies on indivisibles and wrote his most important work, *Geometria indivisibilibus* (not printed until 1635). After turning his attention to astronomy, in 1629 Cavalieri became professor of mathematics at Bologna for a 3-year trial period. He was simultaneously appointed prior at the Jesuati convent of Santa Maria della Mascarella in Bologna. He then became very productive, publishing some 11 books.

The Bologna curriculum included Euclid's *Elements*, the *Theorica Planetarum*, and **Ptolemy**'s *Almagest*, although each professor was free to teach appropriate subjects. Cavalieri, more mathematician than astronomer, focused on the science of numbers. He was one of the first professors at Bologna to disseminate Copernican theory, although he explained it strictly on a hypothetical level due to censorship. To be reconfirmed, Cavalieri published his *Directorium generale Uranometricum*, the exceptional logarithmic tables he had compiled. The work is divided into three parts, devoted to logarithms, plane trigonometry, and spherical trigonometry, respectively. In addition to noteworthy innovations in terminology, the work includes important demonstrations of **John Napier**'s rules of the spherical triangle and of the theorem of the squaring of each spherical triangle that, attributed to Albert Girard, was later claimed by **Joseph Lagrange**. His other works include *Nuova pratica astrologica*. The word "astrological" in the title should not be misconstrued, however, as Cavalieri was opposed to the practice of astrology. Under the pen name of Silvio Filomantio, he wrote *Trattato sulla Ruota planetaria perpetua e dell'uso di quella*, which received mixed criticism. Cavalieri was accused of backing the prejudices of judiciary astrology. In reality, his work deals solely with astronomical, geographical, and chronological subjects, although he used astrological terminology.

Following Cavalieri's death, Bonardo Savi (an anagram for Urbano d'Aviso) printed the work *Trattato sulla Sfera*, which Cavalieri had left in manuscript. The treatise examines astronomical observations, in addition to discussions on the circulation of water and various atmospheric phenomena, which are of great interest at least from a historical standpoint.

In the field of astronomy, we must cite Cavalieri's *Specchio ustorio overo trattato delle settioni coniche* on the properties of parabolic, hyperbolic, and elliptical mirrors, overlooked by his predecessor Magini in his work on spherical mirrors. The section of this work about their application includes new and original concepts: Spherical mirrors are used not only as optical instruments but also as acoustical ones. Moreover, Cavalieri explicitly states the equivalence of the dioptric system (with lenses) and the catoptric system (with mirrors): "if we combine the concave mirror … with the concave lens [diverging eye lens] we should achieve the effect of the telescope." Several scholars have credited Cavalieri with inventing the reflecting telescope before **James Gregory** and **Isaac Newton**.

Afflicted with gout, in 1636 Cavalieri went to the health spas of Arcetri, where he spent the summer discussing mathematics with Galilei. Upon his return, his work suffered because of poor health, envy of other friars in his order, and the fact that the academic senate would have preferred that he compile ephemerides and study astronomy. Unwilling to leave Bologna, Cavalieri turned down the chair at Pisa that Galilei offered as well as Cardinal Borromeo's invitation to move to Milan as a doctor of the Biblioteca Ambrosiana.

Against his volition, Cavalieri became involved in a dispute with Jesuit mathematician Paul Guldin, who accused him of appropriating several of **Johannes Kepler**'s propositions and groundlessly contradicting some of Galilei's assertions. To defend himself, Cavalieri wrote a (unpublished) dialog, preferring to entrust his defense to his work *Trigonometria plana et sphaerica linearis et logaritmica* and to the third of the *Exercitationes geometricae sex*. The former was a pamphlet for students, but was consulted profitably by scientists such as **Giovanni Cassini**, because it summarized problems from his minor works. The latter is an appendix to *Geometria*, extending the method of indivisibles to a large number of applications, also arriving at decidedly original concepts. Examples can be found in the fourth *exercitatio*, where in his discussion about squaring parabolas and cubing the bodies of revolution they generate, Cavalieri closely approaches the formula of integral calculus, while in his fifth *exercitatio*, he applies indivisibles to determining the centers of gravity of bodies with variable density.

Cavalieri extended the applications of geometry to mechanics, physics, and astronomy, propounding them in a series of connected works that, in Cavalieri's own words, were to be read simultaneously: *Compendio delle regole dei triangoli colle loro dimostrazioni*; *Centuria di vari problemi per dimostrare l'uso e la facilità dei logaritmi nella Gnomonica, Astronomia, Geografia ecc.*; and *Nuova pratica astrologica di fare le direttioni secondo la via rationale* to which an *Appendix* was added. These works were then unified in a single volume, to which he added his *Annotations*.

Cavalieri's chair was renewed in 1646, but he was unable to continue teaching for long. The problem with his legs became so severe that he could no longer walk when he died. Cavalieri was buried in the church of Santa Maria di Mascarella, where he is commemorated with a memorial tablet.

In addition to the recognition that the Senate of Bologna, Cardinal Borromeo, Pope Urban VIII, and Ferdinand II of Tuscany attributed to his work, we must also remember Galilei's profound esteem for the Milanese mathematician, referring to him as the Alter-**Archimedes**.

Fabrizio Bònoli

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Cavendish, Henry

Born **Nice, France, 10 October 1731**
Died **Clapham, (London), England, 24 February 1810**

English aristocrat Henry Cavendish's goal was to weigh the world. He succeeded and thereby measured the density of the Earth (1798). The Cavendish experiment is today thought of as a means by which to establish the universal gravitational constant, *G*, and Cavendish is remembered primarily as an experimental physicist. His cousin was **John Michell**, who designed the prototype of what is now called a Cavendish balance.

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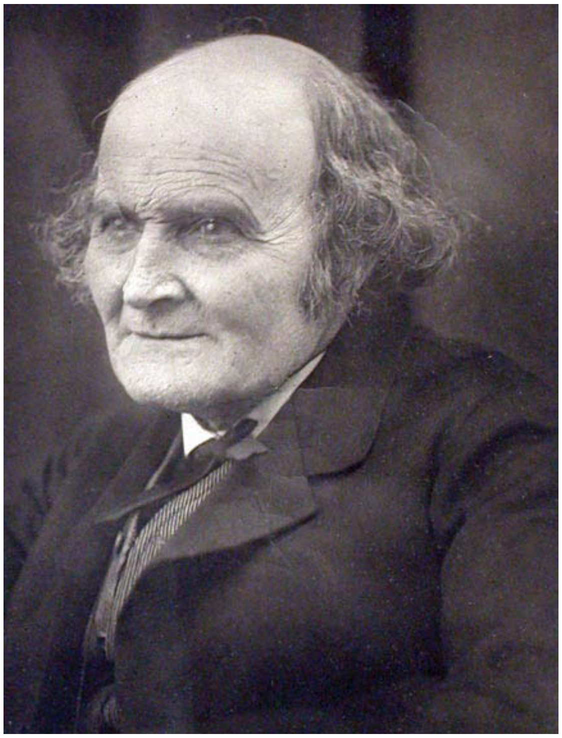
Cayley, Arthur

Born **Richmond, (London), England, 16 August 1821**
Died **Cambridge, England, 26 January 1895**

The mathematical contributions of Arthur Cayley have strongly influenced the development of modern physics and astronomy, on both the smallest and largest scales of the Universe. Cayley, the second son of Henry Cayley and Maria Antonia Doughty, was born while his parents were on a visit to England. His father was a merchant who traded with Russia and lived in Saint Petersburg. He was 8 years old before his parents returned to live permanently in England.



Cayley went to a private school at Blackheath and later attended King's College School in London. His remarkable mathematical abilities were revealed early in life. He was admitted to Trinity College, Cambridge. Graduating as senior wrangler in 1842, Cayley was also awarded first place in the Smith's Prize. He was elected fellow of Trinity College and became an assistant tutor for 3 years. During this time, Cayley was deeply immersed in mathematical research and publication.

On the expiration of his fellowship, Cayley chose the law as his profession; he studied at Lincoln's Inn and was called to the bar in May 1849. After 14 years (1863), he accepted the newly established Sadlerian Professorship of Pure Mathematics at Cambridge University. That same year, Cayley married Susan Moline of Greenwich; the couple had two children.

The remainder of Cayley's life was devoted to research in pure mathematics, theoretical dynamics, and mathematical astronomy. He is considered to be a joint founder, with James Joseph Sylvester, of the theory of invariants and was responsible for creating the theory of matrices. Both areas of Cayley's research have acquired extraordinary significance in the development of 20th-century physics, especially relativity theory and early quantum theory (*e. g.*, matrix mechanics). Cayley also originated the geometry of "higher spaces" (*n* dimensions) and, perhaps most importantly, demonstrated how "metrical geometry" may be reduced to "projective geometry." This important step enabled **Felix Klein** to unify both Euclidean and non-Euclidean geometries into a single, more comprehensive geometry. Cayley's other contributions to astronomy were in the traditional area of physical astronomy, as related to the development of the disturbing function in lunar and planetary theory.

Beyond his mathematical investigations, Cayley assumed active roles in a large number of scientific associations. Between 1859 and

1882, he served as editor of the *Memoirs* and *Monthly Notices of the Royal Astronomical Society*, except for his 2-year term as society president (1872–1874). Cayley was awarded numerous mathematical and scientific honors, including the Royal Medal and the Copley Medal of the Royal Society (London) and the De Morgan Medal of the London Mathematical Society. He was president of the London Mathematical Society, of the Cambridge Philosophical Society, and of the British Association for the Advancement of Science. Cayley was actively involved in mathematical pursuits until his death.

Suhasini Kumar

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Celoria, Giovanni

Born **Casale Monferrato (Alessandria, Piedmont, Italy), 29 January 1842**
Died **Milan, Italy, 17 August 1920**

Giovanni Celoria, Italian astronomer, geodesist, and meteorologist, was well-known for his abilities in numerical calculations, which he applied to the determination of asteroid orbits and to efforts to determine the distribution of stars in space (stellar statistics).

Son of Carlo Celoria and Teresa Beccari, Giovanni had five brothers and one sister. In 1873, he married Rosa Manzi, who was his faithful helpmate until his death. Celoria received his first education at home; he then followed classical studies in his native town and attended Turin University, where, in September 1863, he graduated in engineering.

But Celoria was more attracted by astronomy than engineering. Starting in November 1863, thanks to Lorenzo Billotti (a clever mathematician who counted **Giovanni Schiaparelli** among his students), Celoria was admitted to the Brera Astronomical Observatory (Milan). On 24 April 1864, as a result of his progress, the director of the observatory (Schiaparelli) admitted Celoria to the staff as apprentice astronomer. In 1872 he was appointed astronomer.

Determined not to leave Brera, Celoria refused important offers: in 1884, the directorship of the Beijing Observatory and, in 1893, the directorship of the Arcetri Observatory in Florence. In 1900, succeeding Schiaparelli, he became director of the Brera Observatory, retiring in January 1917.

Soon after his arrival at Brera, Celoria made his first contributions to theoretical astronomy: he calculated the orbits of asteroids and compiled astronomical ephemerides. Starting in 1773, the Brera Observatory had published every year the *Effemeridi Astronomiche,* and Celoria devoted himself to this work up to the last volume published in 1874. From 1865 to 1866, he spent a short time in Berlin, where **Otto W. Struve** worked, and in Bonn, where **Friedrich Argelander** was professor, to improve his calculation methods and to practice observational astronomy.

Back in Milan, Celoria worked again on the motion of celestial objects. He calculated several orbits of minor planets including (69) Hesperia, (73) Klytia, and (31) Euphrosyne, and comets including C/1864 N1 (Tempel), C/1864 O1 (Donati–Toussaint), and C/1864 R1 (Donati). Celoria studied theoretical astronomy his whole life, often using his own observations as a basis for his calculations. At the same time, he also observed various celestial phenomena, such as lunar eclipses, stellar occultations by the Moon, and transits of Venus.

From 1864 to 1872, using a meridian circle, Celoria carefully measured the positions of the stars with declinations from −2° up to +6° in order to complete Schiaparelli's work. These observations, with some others collected from 1877 to 1883 with an upgraded instrument, were processed to produce the stellar catalog published by Schiaparelli and him in 1901.

Celoria made a significant contribution to the studies of the real distribution of the stars in space, a problem extensively discussed between 1850 and 1880. From 1873, for 3 years, he carried out more than 27,000 surveys to investigate the distribution of the stars down to 11.5 magnitude. He counted more than 200,000 stars, carrying out careful statistical work that may be placed historically between **William Herschel**'s counts and Argelander's *Bonner Durchmusterung*. An important result achieved by Celoria with these data, which benefited **Hugo von Seeliger** in his theoretical studies, was a model of the structure of the Milky Way. According to Celoria's hypothesis, the Milky Way Galaxy is composed of two single rings joined one to the other.

Celoria also carried out measurements of 220 double star systems; for several of these he calculated the orbital elements. The instruments used were two Merz refractor telescopes: one 218 mm in aperture from 1886 and one from 1901, 489 mm in aperture.

A forceful and persuasive speaker, as well as an elegant writer, Celoria was a successful popular writer. For Italian newspapers and magazines (*Il Corriere della Sera*, *Bollettino della Società Geografica Italiana*, *etc.*) he wrote articles on current astronomy issues. For 36 years, he collaborated with the magazine *Annuario Scientifico ed Industriale,* writing reports on the most relevant discoveries in various branches of astronomy.

Among Celoria's interests, history of astronomy had a strong role. His reputation in that field was due to three memoirs on a study of ancient solar eclipses (published in 1875, 1876, and 1880). For the third one, he won the Royal Award of the Reale Accademia dei Lincei. Celoria was known also for his study of the work of the Italian astronomer **Paolo Toscanelli** (published in 1894). On the whole, Celoria's activity includes about 80 notes and memoirs, some of which were published in *Astronomische Nachrichten*.

Celoria was actively engaged in public affairs; as public-education committee chairman, he managed the administrative and scientific renewal of the Museo Civico di Storia Naturale (Milan). In 1909, he was appointed Senator of the Reign. Celoria was a member of several institutions and societies: the Reale Accademia dei Lincei, the Quaranta of the Società Italiana delle Scienze, the

Royal Astronomical Society of London, and the Istituto Lombardo Accademia di Scienze e Lettere of Milan.

Antonella Testa

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Cellarius

Kneller, Andreas

Celsius, Anders

Born **Uppsala, Sweden, 27 November 1701**
Died **Uppsala, Sweden, 25 April 1744**

Anders Celsius is known not only for "degrees Celsius" but also for degrees of latitude that helped verify the Newtonian universe.

Celsius succeeded his father Nils Celsius as Uppsala University's professor of astronomy in 1730. (Both grandfathers were Uppsala professors.) Early publications discussed terrestrial surveying. In 1732 he undertook a tour of European observatories that ultimately resulted in obtaining instruments for a modern astronomical observatory at Uppsala University in 1741. Celsius began his astronomy career in earnest while at Nuremberg, with the publication of his 1732 auroral observations. His travels also led to participation in **Pierre de Maupertuis**'s 1736 Lapland expedition.

One prediction of **Isaac Newton**'s gravitational theory was that the Earth was an oblate spheroid in shape. Thus, measuring the length of 1° of latitude in both far northern Sweden and near the Equator should result in different values. This proved to be the case, with the northern degree longer, thereby confirming Newton.

Back in Uppsala, Celsius published *De Observationibus pro Figura Telluris Determinanda* (1738). He served as secretary of the Royal Society of Sciences at Uppsala University. His astronomical work also involved stellar photometry and calendar reform. In the former his successful photometer, used on 300 stars, consisted of viewing through glass filters, which Celsius stacked until they extinguished a star's light. In the latter he was unsuccessful (within his own lifetime) at attempts to convert Sweden to the Gregorian calendar.

Observatories of the time commonly undertook magnetic and meteorological measurements as well as astronomical ones. Ironically, Celsius is better remembered today for these auxiliary labors: he and **Olof Hiorter** were among the first to correlate magnetic compass deviations with the aurora borealis. Still, Celsius's most lasting fame no doubt comes from the temperature scale he used to make thermometer readings.

Thomas Hockey and *Richard A. Jarrell*

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Ceraski, Vitol'd [Witold] Karlovich

Tserasky [Tzeraskii], Vitol'd [Witold] Karlovich

Cerulli, Vincenzo

Born **Teramo, (Abruzzo, Italy), 26 April 1859**
Died **Merate, (Lombardy), Italy, 30 May 1927**

Vincenzo Cerulli's vast wealth enabled him to establish a private observatory near Teramo, Italy, where he first proposed his optical theory to explain the observations of canals on Mars. This examination of the processes of vision and perception in the rendering of planetary detail entailed a pioneering investigation of the use of the human eye as a scientific instrument.

Cerulli's parents belonged to the most prominent and wealthy families of the Teramo region. He studied physics under **Lorenzo Resphigi** at the University of Rome, graduating in 1881. He then spent 4 years in Germany, where he received training at the observatories in Bonn and Berlin, and at the Rechen Institut, where he learned methods of orbital calculation. After serving as a volunteer astronomer at the Collegio Romano in Rome under its director **Pietro Taccini**, Cerulli returned to Teramo. Not having to worry about means of support, he was in the enviable position of being completely independent; he did not need to seek an official position, but instead pursued a career in science according to his own predilections and with the ability to fund his own research.

On the hill Collurania (the hill of Urania) outside of Teramo, Cerulli established an observatory equipped with a fine 16-in. Cooke refractor. It was "rare among Italian observatories, an astronomical establishment … not founded for the use of king, prince, or pope, but to indulge the passion of a private citizen of Teramo" (Horn-D'Arturo).

Like **Percival Lowell** and **René Jarry-Desloges**, also wealthy amateurs who established their own observatories, Cerulli turned heart and soul to the study of the planet Mars during the heyday of the Mars furor in the 1890s. For a decade and a half, **Giovanni Schiaparelli** had published a series of detailed memoirs and maps documenting the planet's surface markings based on observations made at the Brera Observatory in Milan during the oppositions from 1877 through 1888. Schiaparelli announced that a network of intersecting lines, the famous *canali*, tessellated the planet's surface. On the basis of his own study of Mars with the Cooke refractor in 1896 and 1898, Cerulli confirmed the impression of many of these linear features. However, in contrast to Schiaparelli, Cerulli did not regard these perceived forms to represent the true topography of the planet's surface.

Rather, Cerulli enunciated an optical theory to account for the impressions of canals on Mars. The actual surface of the planet, he suggested, was mottled with various spots and streaks, like any other natural surface. These forms, however, were too minute to be clearly resolved and lay at or just below the threshold of perception. The eye imposed its own order (schemas) on this bewildering array, according to Cerulli. During the first moments of telescopic inspection, the perception was confused and later it became sorted into a settled and apparently complete image. This sequence of perceptual stages corresponded to the pre-Schiaparellian and Schiaparellian visions of Mars.

The implication of Cerulli's theory was that an even truer view of the planet would emerge with better telescopic resolution. At a time when most astronomers resisted any conclusion that the response of the eye might not be fully trustworthy, Cerulli pointed out that the eye needed to be analyzed no less than any other instrument of scientific research. Cerulli's work required careful introspection and attention to the processes of observation of a kind scanted by earlier areographers.

On the whole, Cerulli's work on Mars, which he published privately, was seen as sharply critical of the Milan astronomer's findings. Indeed, Cerulli and Schiaparelli engaged in a stimulating exchange of views on Mars. They respected each other, and were in many ways alike – like Schiaparelli, Cerulli preferred to use a Socratic method in teaching rather than giving formal lectures. Both were great admirers of the classical Latin writers and wrote dedicatory verses in Latin. It cannot be said that Schiaparelli ever fully embraced Cerulli's perspective, although he came close to doing so in 1907. However, he then seems to have had a change of heart and returned to his original views by the time he died in 1910. Cerulli's views were largely borne out by the high-resolution images of Mars obtained by **Eugène Antoniadi** with the 33-in. refractor of the Meudon Observatory in 1909 (and, much later, by spacecraft findings). Although Antoniadi had the advantage of a powerful instrument, Cerulli always maintained that powerful instruments were not prerequisites for scientific research. In analyzing the process of perception, Cerulli had already seen more deeply into the nature of the true spots and streaks on the Martian surface than had many observers using large instruments.

Although Cerulli's most original work involved his "optical theory" of the canals of Mars, he also devoted a great deal of effort to positional astronomy, both the visual and photographic observation of asteroids, comets, and double stars, and to orbit calculation. In 1910, he discovered an asteroid that he named *Interamnia*, from the Latin name for Teramo. That same year he recovered comet 4P/Faye. About this time Cerulli became interested in attempts to determine the mass of the galactic system from the Sun's motion, an area of research in which he anticipated some of the conclusions of **Jacobus Kapteyn**. He was not, however, enthusiastic about **Albert Einstein**'s gravitational theory: "In spite of fashion," he once wrote:

> I remain faithful to **[Isaac] Newton**, and consider the introduction of the ultrasensible (four-dimensions, the curvature of space) to be a step backward – brilliant as it may appear to be from the mathematical point of view – a return to binding Urania in the bands of what Newton regarded as the 'hypotheses of metaphysics '… .

However, Cerulli's disbelief of Einstein's theory did not prevent him from rigorously calculating the bending of starlight Einstein predicted near the Sun.

Cerulli seems to have been remarkably able to sustain himself from his own intellectual resources. If he was ever lonely in his observatory among the rolling Abruzzi hills, he gave little indication of it. Yet gradually his private research was co-opted by duties in national and international astronomical organizations: he served as president of the Astronomical Society of Italy, was elected vice president of the International Astronomical Union, received honorary professorships in the University of Rome and at the Vatican Observatory, and was elected a member of the Royal Academy of Lynxes. He held memberships in the Royal Commission of Geodesy, the Academy of Sciences of Torino, and the Pontifical Academy of Sciences.

In 1917, Cerulli decided to donate his observatory on Collurania to the state, on the condition that the observatory remain devoted to the independent study of astronomy. The Italian government accepted the bequest in 1919, and the observatory remains open to the present day.

William Sheehan

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Cesi, Federico

Born **Rome, (Italy), 1585**
Died **Acquasparta, (Umbria, Italy), 1630**

Prince Federico Cesi founded the Academy of the Lincei. He helped **Galileo Galilei** with his publications; however, Cesi's own book, championing the fluidity of the heavens, was never published.

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Chacornac, Jean

Born **Lyons, France, 21 June 1823**
Died **Villeurbanne, Rhône, France, 23 September 1873**

Jean Chacornac was a dedicated observational astronomer. He began a career in commerce in Lyons and then Marseilles, where **Benjamin Valz**, director of the Marseilles Observatory, allowed him to use the telescopes. Chacornac studied sunspots and in 1852 discovered a comet (C/1852 K1). Thenceforth he devoted himself fully to astronomy, assisting Valz in the discovery of minor planets and the essential precursor of ecliptic mapping.

Chacornac transferred to Paris as part of **Urbain Le Verrier's** reform of the Paris Observatory in 1854, where most notably he published 36 maps of the ecliptic (1860–1863). Chacornac was renowned as a tireless worker and was highly thought of by scientists such as **Jean-Bernard-Léon Foucault**, but he was one of the numerous astronomers who in due course incurred Le Verrier's displeasure.

In 1863, Chacornac retired to Villeurbanne, near Lyons, where he built a private observatory with a Foucault-style reflecting telescope and returned to solar observations. From these he incorrectly concluded that sunspots were caused by erupting chains of volcanoes.

William Tobin

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Chalcidius

Flourished **4th century**

Chalcidius's popular commentary on **Plato**'s *Timaeus* included some epicycle theory. It was an important vehicle for the transmission of Platonic cosmology to the Middle Ages.

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Challis, James

Born **Braintree, Essex, England, 12 December 1804**
Died **Cambridge, England, 3 December 1882**

James Challis was a Cambridge University astronomer best known for his failure to discover Neptune in the summer of 1846. Educated at Cambridge, where he was a senior wrangler, Challis was elected a fellow of Trinity College in 1826. He became a *protégé* of the strong-willed and domineering **George Airy**, after Airy became director of the Cambridge University Observatory in 1828. In 1830, Challis was ordained and also assumed the position he was to hold until the end of his life, Plumian Professor of Astronomy. He married the following year. On Airy's appointment as Astronomer Royal in 1836, Challis succeeded to the observatory directorship.

By all accounts, Challis was an honest, hard-working man who seems to have aspired to nothing more than to doing his duty. While this bank clerk's mentality served him well in some ways, it would tell against him when he had his greatest opportunity to discover Neptune, whose existence had been surmised by Challis's younger colleague, **John Adams**, and by **Urbain Le Verrier**.

At first Challis' search was delayed by his attempt to catch up on the reduction of a horde of comet observations; the first part of 1846 had been rich with comets, including, most notably, 3D/Biela, which broke apart. When Airy urged haste upon him, he took up the search in a thorough but plodding fashion. The instrument used was the 12-in. Northumberland refractor at Cambridge, and Airy instructed Challis to sweep a generous band of the zodiac, 30° long by 10° wide, centered roughly on the position given in the paper Le Verrier had published in the *Comptes rendus* on 1 June. His observations would have been suitable for drawing up a star map, and he later claimed that if only he had one, he might have succeeded. Ironically, he *did* have one, although he did not use it. Challis had found Hour XXII of the Berlin Academy star map, by **Friedrich Argelander**, in the Cambridge Library before starting his search; it covered part of the region in question, including that in which the planet was actually passing. Thus his excuse was disingenuous to some degree.

In the course of routine observations, Challis actually recorded the planet twice, on 4 and 12 August 1846, but failed to recognize it since he did not compare the observations. He reported to Airy in early September that the work was slow and would not be completed that year. Challis was always vastly overworked – with teaching and maintaining his ambitious meridian program with the mural and transit circles – and he did not proceed with enthusiasm in his additional task, in which he never had any confidence.

In the end, the actual discovery of the planet was made by **Johann Galle** at Berlin on 23 September 1846, on the basis of Le Verrier's calculations. Before news reached England, Challis missed yet another – his last – chance to make an independent discovery. He had been urged to look for a small disk among the stars, based on Le Verrier's recommendation in his last-published paper in the *Comptes rendus*, which had appeared on 31 August 1846. While sweeping, Challis noted one star that appeared to have a disk. But he was called away to tea, and by the time he had a chance to return to the telescope, the sky had clouded up. Soon afterward Challis learned from England's **John Hind**, the first astronomer in England to knowingly see the planet, that "Le Verrier's planet is now discovered" and that "our searches are now needless." One can only imagine that he must have been devastated.

Challis made no friends in France when he and Adams proposed their own names for the new planet– Oceanus – as if they had a right to the privilege of naming it. The name originally proposed by the French, Neptune, was adopted. In the postdiscovery inquest, Airy and Challis had to defend themselves against what started out as a university squabble but soon became a national and then an international scandal. Airy mounted as effective a defense as was possible; Challis, in the end, was made to look like a bumbler, which probably served him well. He was deemed too insignificant to go after.

Challis gave an account of his role that was dignified and notable, at least, for its honesty. He summed up his attitude about Adams's and Le Verrier's mathematical positions of the unknown planet: "It seemed so novel a thing to undertake observations in reliance upon merely theoretical deductions, and while much labour was certain, success appeared very doubtful." Challis was not hounded to the degree that Airy was post-Neptune-mortem.

Challis seems to have been a thoroughly likeable personality; he embodied the ideals of Victorian astronomy, which emphasized routine observations and duty. An unstinting and productive worker, he wrote over 200 papers on mathematical, physical, and scientific subjects and published 12 hefty volumes of *Observations Made at the Observatory of Cambridge* (1832–1864). Except for the notable lapse of 1846, Challis seems to have been a singularly faithful watcher at his post. He was succeeded by Adams as director of the observatory in 1861, but continued to occupy the Plumian Chair until his death.

William Sheehan

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Chalonge, Daniel

Born **Grenoble, Isère, France, 31 January 1895**
Died **Paris, France, 28 November 1977**

French observational astronomer Daniel Chalonge is remembered primarily for his work on determining the properties of stars from relatively broadband spectral information. His thesis work in Paris was directed by French physicists Aimé Cotton and **Charles Fabry**. Chalonge had several dozen students, some of whom (especially Lucienne Divan) have also contributed to the study of stellar classification.

In 1941, Chalonge and **Daniel Barbier** announced a way of measuring the temperature, surface gravity (related to luminosity and mass), and abundance of heavy elements in stars from information on color, rather than detailed, high-resolution spectra. They defined three parameters describing the behavior of spectra near a wavelength where hydrogen gas is a strong absorber. Their parameters were eventually shown to be well correlated with stellar temperatures, surface gravities, and compositions found from spectra, for instance the two-dimensional classification developed by William Morgan and Philip Keenan.

The third (composition) parameter can be shown to pick out (1) subdwarfs, which Joseph Chamberlain and **Lawrence Aller** showed to be poorer than the Sun in heavy elements by factors of 10–100, and (2) stars with strong lines of some metals, called Am stars. The subdwarfs are part of an ongoing process by which heavy elements are produced by nuclear reactions in stars, while the Am stars result from complex atmospheric processes. The work of Chalonge with V. Kourganoff just after World War II helped to establish firmly the earlier conclusion of **Rupert Wildt** that the main source of opacity in the atmospheres of cool stars is H^-, the ion consisting of a hydrogen atom plus an electron borrowed from a metal atom. Thus stars with many such metal atoms look redder than others of the same temperature but with fewer such atoms.

The system devised by Barbier, Chalonge, and Divan [BCD] was never widely applied. This was probably because they did not have ready access to good observing sites. However, the system contributed directly to the definitions of other photometric systems (especially that of **Bengt Strömgren** and that used at the Geneva Observatory) that have advanced our understanding of the structure and evolution of stars.

Roger Cayrel

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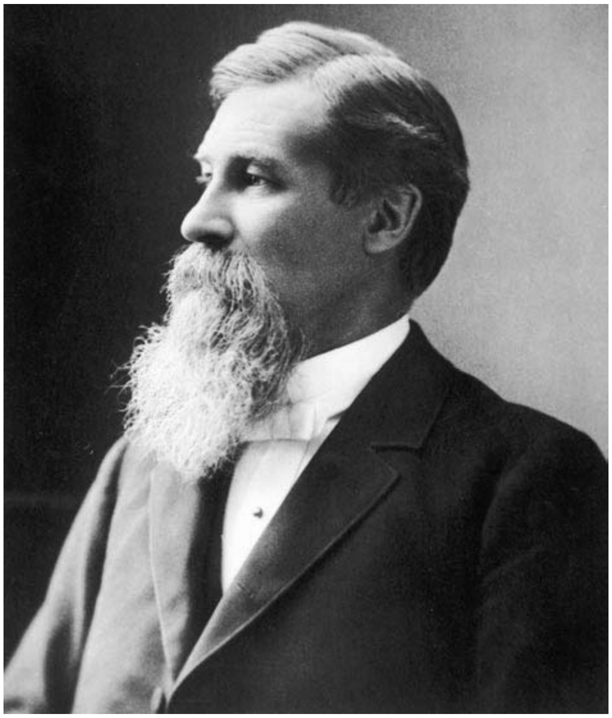
Chamberlin, Thomas Chrowder

Born **Mattoon, Illinois, USA, 25 September 1843**
Died **Chicago, Illinois, USA, 15 November 1928**

Thomas Chamberlin, American geologist and planetary scientist, was best known within astronomy as the senior proposer of the Chamberlin – Moulton hypothesis for the formation of the Solar System, in



which planetary systems were supposed to result from the close encounters or collisions of previously existing stars. This alternative to the nebular hypothesis of **Immanuel Kant** and **Pierre de Laplace** was intended to account for most of the angular momentum of the Solar System being found in the orbits of the planets and very little in the rotation of the Sun. Modern astronomy favors a later version of the nebular hypothesis and the loss of angular momentum in stellar winds. Chamberlin was also an early, firm exponent of a timescale of billions (rather than tens of millions) of years for the Earth, in opposition to **William Thompson** (Lord Kelvin) and other physicists, whose shorter timescale came from the assumption that stars are powered only by gravitational contractions.

Thomas Chamberlin was the third of five sons. His father John Chamberlin, a farmer and Methodist preacher born near Camden, North Carolina, had chosen to move north to Illinois partly on account of his strong antislavery views. John Chamberlin lived for a while in Palatine, Illinois, where he met and married Cecilia Gill, a young lady of Scottish descent who was from Lexington, Kentucky. John then moved once more and settled with his wife and sons on a farm near Beloit in southern Wisconsin, because he felt it would be a more favorable place in which to raise his children. Although a man of limited academic education, John Chamberlin was an independent thinker and reader in theology and philosophy, who made every effort to provide educational opportunities for his sons that he himself had not enjoyed. To make this possible, the family moved for a time from the farm to the town of Beloit, so that the boys could attend Beloit College Academy.

Following graduation from the College Academy, Thomas Chamberlin entered Beloit College in 1862. The curriculum was based on the traditional classical model with its focus on Latin, Greek, and mathematics. It is not surprising, given his upbringing, that Chamberlin was greatly interested in philosophy and mathematics. He was also a deeply religious young man and found that his theological beliefs made him initially skeptical about the subject of geology. As he set out to investigate the subject, he gradually developed a strong interest in geology that was greatly influenced by professor Nason, his first geology teacher. Chamberlin's later tribute, published as a "Memoir of Henry Bradford Nason" in the *Bulletin of the Geological Society of America*, expressed his gratitude to Nason for awakening what had become the dominating interest of his life.

Following his graduation from Beloit College in 1866, Chamberlin became principal of the Delavan (Wisconsin) High School. In 1867, he married Alma Isabel Wilson of Beloit who always remained a wonderful companion and inspiration to him. They had one son who was named Rollin after Chamberlin's dear pupil, loyal friend, and close collaborator, Rollin D. Salisbury. After 2 years at Delavan High School, Chamberlin felt the need for further scientific study and entered the University of Michigan. There he became a student under Alexander Winchell, a distinguished geologist of his day, an experience that rekindled Chamberlin's interest in geology. After a year at Ann Arbor, Chamberlin returned to Wisconsin in response to a call to teach at the State Normal School at Whitewater, Wisconsin. Three years later, he accepted a position as professor of natural sciences at Beloit College and started there in the fall of 1873. There he eventually was made professor of geology.

A landmark event in Chamberlin's life occurred in 1873, when Governor C. C. Washburn instituted a complete geological survey of Wisconsin and appointed Chamberlin as one of the assistant geologists. Chamberlin was assigned to the southeast section of the state, at the time regarded as an unpromising area. However, Chamberlin's intellectual curiosity and dedication to the study of glaciation led him to discover therein an exciting area of research that shaped the future course of his scientific career. From 1876 to the completion of the survey in 1882, Chamberlin served as chief geologist and managed all of the administrative affairs in addition to his own part-time work as professor at Beloit College. The survey culminated in the publication of the outstanding four volumes on the geology of Wisconsin, which provide an unparalleled account of the geology of the state. Following the successful end of the Wisconsin survey, Chamberlin was appointed in 1881 as chief geologist in charge of the glacial division of the United States Geological Survey, a position he held until 1904.

In 1887, Chamberlin was called to the presidency of the University of Wisconsin. Under his remarkable leadership the university saw significant progress and achievement. Much to their disappointment, however, when he was offered the position as head of the Department of Geology in the University of Chicago in 1892, Chamberlin accepted in the hope that it would allow him to return more fully to his scientific pursuits. Although he was not totally free of administrative responsibilities, since he served during this time as director of the University Museum and as dean, he remained in the position till his retirement in 1919. Shortly after the opening of the department, in 1893, Chamberlin founded *The Journal of Geology*, a highly respected journal for which he served as editor-in-chief over the next 30 years. In 1894, he accompanied the Peary auxiliary expedition to Greenland and published a series of studies on the glaciers of Greenland. Chamberlin was also one of the commissioners selected by the university to conduct a philanthropic survey mission to China, which ended in 1909.

Chamberlin held several prestigious positions and memberships in educational societies. He was a member of the Wisconsin Academy of Science, Arts and Letters (president: 1885–1886), the Geological Society of America (president: 1895), the Chicago Academy of Science (president: 1897–1915), the Illinois Academy of Science (president: 1907), the American Association for the Advancement of Science (president from 1908), the National Academy of Sciences, the American Philosophical Society, and the American Academy of Arts and Sciences among others.

Chamberlin was awarded many honors including medals for geological publications at the Paris Exposition of 1878 and 1893. He received the Helen Culver Medal of the Geographic Society of Chicago, the Hayden Medal from the Academy of Natural Sciences of Philadelphia, and the Penrose Medals in 1924 from the Society of Economic Geologists and in 1927 from the Geological Society of America.

Chamberlin became established over the years as the nation's leading glaciologist and is probably best known for his investigations related to glacial geology. His study of glacial climates led him to explore the larger scientific implications of glaciation and the geologic past. He was particularly interested in the causes of glacial climates; this interest eventually led him to study the evolution of the Solar System and the probable part it played in the Earth's climates and in the formation of Earth itself. His scientific spirit drew him from geology into the worlds of physics and astronomy. His careful studies led Chamberlin to discover facts that he found to be inconsistent with the Laplacian hypothesis that a steaming hot atmosphere surrounded the Earth during its early stages. He collaborated in this study with professor **Forest Moulton**, a University of Chicago mathematician and astronomer, whose mastery of celestial mechanics and mathematics contributed to the success of their investigations. Chamberlin and Moulton had abandoned Laplace's ideas and had developed "the planetesimal hypothesis," which eventually replaced existing theories for the origin of the Earth. The planetesimal hypothesis resulted in the development of a new geologic philosophy, which had a tremendous impact on geologic thought and absorbed Chamberlin for the rest of his life.

One of Chamberlin's chief publications with Rollin Salisbury was *Geology* in three volumes between 1904 and 1906, intended to be a comprehensive textbook of geology in light of the new geologic philosophy. In response to a request for a less technical presentation, Chamberlin later published *The Origin of the Earth* (Chicago: Chicago University Press, 1916). His last major publication was started as a revision of *The Origin of the Earth* and was to have comprised two volumes delineating the origin of the Solar System and the growth of the Earth. The first of these volumes, entitled *The Two Solar Families,* was published on his 85th birthday in 1928. It discussed the origin of the Solar System. Unfortunately, he was taken ill and died.

Collections of Chamberlin's papers are preserved in the University of Chicago Library and the archives of the Wisconsin Historical Society.

Raghini S. Suresh

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Chandler, Seth Carlo, Jr.

Born **Boston, Massachusetts, USA, 16 September 1846**
Died **Wellesley Hills, Massachusetts, USA, 31 December 1913**

As a practical astronomer Seth Carlo Chandler discovered the periodic motions in the Earth's polar axis, now known as the Chandler wobble, and made important contributions in the fields of variable star and cometary astronomy. Chandler also served as the editor and publisher of the *Astronomical Journal*.

The son of Seth Carlo and Mary (*née* Cheever) Chandler of Boston, Massachusetts, Chandler demonstrated his mechanical and mathematical abilities well before he graduated from the Boston English High School in 1861. During his last year in school, Chandler worked part-time as a computing assistant to **Benjamin Peirce** and was apparently attracted to astronomy in that experience. After his graduation, Chandler was employed as the personal assistant of **Benjamin Gould**, who was at that time engaged in longitude determinations for the United States Coast Survey. The two remained close friends for the remainder of Gould's life.

Chandler was employed formally as an Aide by the Coast Survey in 1864. He traveled to Calais, Maine, to participate in the important determination of its longitude based on time signals received over the trans-Atlantic cable from the Royal Observatory Greenwich via Liverpool. Chandler also traveled to Galveston, Texas, as part of his survey work in the next few years. The longitude in Galveston was again determined by time–signal coordination over telegraphic lines, this time with the Coast Survey in New Orleans.

When Gould left to found the Argentine National Observatory in Cordoba, Argentina, in 1869, he invited Chandler to accompany him. However, Chandler had in the meantime become engaged to be married in 1870 and declined the opportunity. Instead, he capitalized on his mathematical abilities and computing experience to become an actuary for Continental Insurance Company in New York City. His success in this new occupation is evident from the fact that only 7 years later Chandler returned to Boston as a consulting actuary for Union Mutual Life Insurance Company, and by 1881 he had, in effect, retired from the business world to take up astronomy full-time. He moved with his family to a home very near the Harvard College Observatory [HCO] in Cambridge, Massachusetts. For a few years, Chandler took part in HCO work at a nominal salary.

While working at HCO, Chandler initiated studies of the change in latitude, his most important work. The almucantar, an instrument designed to relate the positions of stars to a small circle centered at the zenith rather than to the meridian, was conceived by and constructed for Chandler during this period. With this new instrument Chandler discovered the latitudinal variation now known as the Chandler wobble. On the basis of his observations on the movements of the celestial positions of stars all around the zenith, Chandler reported that latitudes on the Earth were varying, with an amplitude of 0.3″ and a period of 14 months. This result was similar to that obtained at about the same time by **Karl Küstner** from his studies of the constant of aberration at Berlin, but Küstner's observations failed to detect the periodicity or establish the direction of motion. Chandler continued to make measurements and refined his theory based both on his own results and on those derived from historical latitude observations at a number of other observatories. In the work with historical records, he discovered an additional term with the period of 12 months. Although other researchers criticized Chandler's results, **Simon Newcomb** showed that these periodic variations were induced by the fact that the Earth is not a solid body.

In addition to his work on latitude variation, Chandler was an active observer of comets and variable stars. His interest in these subjects carried over into his editorial work on the *Astronomical Journal*. From 1886, when Gould began publishing it for the second time, Chandler assisted Gould with editorial work on the *Journal*. When Gould died suddenly in November 1896, Chandler immediately stepped into the roles of editor and publisher of the *Astronomical Journal,* occasionally supporting the cost of its publication from his own funds. Chandler continued in those roles until the journal was turned over to **Lewis Boss** at the Dudley Observatory in 1909. Chandler assisted with the journal for several years thereafter as an associate editor.

While editing the *Astronomical Journal*, Chandler computed and published orbits for every comet discovered and reported to the journal. He was also aggressive in assembling and publishing observations of variable stars and computed elements for their variation from available data. These elements were included in three valuable catalogs of known variable stars published in the journal in 1888, 1893, and 1896.

Chandler joined with John Ritchie Jr. to edit the *Science Observer*, an interesting journal of the Boston Amateur Scientific Society that flourished in the 1870s and 1880s. While the ostensible purpose of the journal was to provide a record of amateur science in Boston, and it did carry a few articles on chemistry and other fields, it is clear that astronomy was the dominant interest of both Chandler and Ritchie. At the time, the dissemination of astronomical discoveries by telegraphic service was faltering because of mistakes in description of information. Chandler and Ritchie proposed a simplified but workable code to facilitate the transmittal of correct information by astronomers. **Edward Pickering**, director of HCO, embraced this coding system and announced that Chandler and Ritchie were affiliated with the observatory and that Harvard would henceforth assume a coordinating role in disseminating telegraphic news to 50 observatories around the world.

As an editor of the *Science Observer*, Chandler encouraged the scientific aspirations of many fine amateur astronomers. His network of amateurs included meteor and variable star observers like Edwin F. Sawyer and Paul S. Yendell, photometrists **Henry Parkhurst** and John A. Parkhurst, and comet and planetary observers like the young **Edward Barnard**, **William Brooks**, and John H. Eadie. More than any other individual during this period, Chandler deserves credit for fostering the growth of an important network of amateurs who cooperated with professionals in their pursuit of astronomical science.

Chandler was elected to the National Academy of Sciences and received that organization's Watson Medal in 1895 as well as the Gold Medal of the Royal Astronomical Society in 1896. He received an honorary Juris Doctor degree from DePauw University in 1891.

K. Sakurai

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Chandrasekhar, Subrahmanyan

Born **Lahore, (Pakistan), 10 October 1910**
Died **Chicago, Illinois, USA, 21 August 1995**

Indian–American theoretical astrophysicist S. Chandrasekhar shared the 1983 Nobel Prize in Physics (with **William Fowler**) for work done in the 1930s, which established an absolute upper mass limit, now called the Chandrasekhar limit, for an astronomical object in which the pressure support comes from electrons being crowded as closely together as quantum mechanics permits. This limit applies to white dwarf stars, such as the Sun will eventually become, and to the cores of more massive stars that then collapse into neutron stars or black holes.

Chandrasekhar came from a scientific background, being the nephew of Nobel Prize winner (Physics: 1930) C. V. Raman. He received a first degree in 1930 from Presidency College, Madras (now Chennai), India, by which time he had published his first paper, on Compton scattering of energetic photons by stationary electrons. A government of Madras scholarship enabled him to go to Cambridge University, and some of the calculations leading to his most famous result were actually carried out on the long voyage from India to England.

Working under **Ralph Fowler**, Chandrasekhar wrote a dissertation on the structure of stars (in a particular approximation called a polytrope) when they were distorted by rotation or the close proximity of another star, receiving his degree in 1933. A fellowship at Trinity College, Cambridge, followed. He returned briefly to India in 1936 to marry a fellow physics student from Madras, Lalitha Doraiswamy, and one might reasonably have expected them to remain indefinitely in Cambridge. The later years there were, however, shadowed by a serious controversy with **Arthur Eddington.**

In 1937, the Chandrasekhars moved to the University of Chicago, where he was initially a research associate, then assistant professor, and retired as the Morton D. Hull Distinguished Service Professor in 1985, but remained scientifically active until his last year. For the first couple of decades of his association with Chicago University, Chandrasekhar was at its Yerkes Observatory, in Williams Bay, Wisconsin, where many of the astrophysics students worked, but he commuted weekly to Chicago to teach there as well, finally settling at the university in 1964.

The disagreement with Eddington arose when Chandrasekhar folded both special relativity and general relativity into his considerations of the internal structure of white dwarfs, leading to a different relationship between pressure and density, called relativistic degeneracy, the existence of which Eddington simply denied. He therefore also refused to accept that there would be an upper limit to the possible mass of such dead stars, beyond which something else must happen (which we now call gravitational collapse). The two remained on good terms until Eddington's death, but it would not have been easy for them to work in the same institution, even if Cambridge University had been more hospitable than it then was to dark-skinned scholars.

At Chicago, Chandrasekhar turned his attention sequentially from one major area of theoretical astrophysics to another. It is sometimes difficult to determine just how much was the input of his students and other colleagues in these programs (most of which ended with a single-author book). Norman Liebowitz is fully credited in the 1969 *Ellipsoidal Figures of Equilibrium*, which deals with the stability and oscillations of rotating fluid spheres (one way of approximating complex stars), but that is not the case with Guido Munch, who coauthored several of the papers leading up to the 1949 *Radiative Transfer*, dealing with how energy works its way from the center of a star to the layers we see. Munch wrote several of the chapters in the book, yet is acknowledged only by indirection and as the person who prepared many of the drawings in the text.

Some of Chandrasekhar's important results from these many investigations were:

(1) a rigorous description of the relationship between matter and radiation inside stars (*Stellar Structure*, 1939);

(2) an upper limit to the mass possible in the inert core of a star before another nuclear reaction must start, the core begins to contract, or the star becomes a red giant (the Schoenberg–Chandrasekhar limit of 1942, with student M. Schoenberg);

(3) the concept of dynamical friction (*Principles of Stellar Dynamics*, 1942) in which a star moving in a cluster is slowed down by its own tidal wake;

(4) an instability in hot, magnetized gases that turns out to be important in the structure of accretion disks around white dwarfs, neutron stars, and black holes (*Hydrodynamic and Hydromagnetic Stability*, 1961); and

(5) a number of theorems concerning the mathematical structure of black holes with rotation and electric charge (Kerr and Riessner–Nordstrom black holes) and the stability of these structures (*The Mathematical Theory of Black Holes*, 1983, which Chandrasekhar himself suspected he might be writing for later generations, the concepts and mathematics being too dense for many of his contemporaries to penetrate).

During the last few years of his life, Chandrasekhar became interested in the work of **Isaac Newton** and the methods used in deriving the results in Newton's *Principia*. He recast many of Newton's propositions in modern notation, publishing the results as *Newton's Principia for the Common Reader* (1995). Consistent to the end, Chandrasekhar greatly overestimated that with which "common readers" were likely to be able to cope.

Chandrasekhar was the Ph.D. advisor of 46 students at Yerkes Observatory and the University of Chicago, including Margaret Krogdall, Marjorie Harrison, Merle Tuberg, and other women (an unusually large number for the time), and at least two men who became in due course directors of major observatories, Donald Osterbrock (Lick) and Guido Munch (Calar Alto). He served as councilor of both the American Physical Society and the American Astronomical Society, but his most impressive contribution to the community was unquestionably his 19 years as managing editor of the *Astrophysical Journal*, an important publication when he took it over in 1952, but the world leader in the field by 1971, when he handed it over to Helmut Abt.

In addition to the Nobel Prize, Chandrasekhar received more honorary degrees than he himself cared to tabulate. He was presented with medals from the United States National Academy of Sciences, the Royal Society (London), the Indian National Academy of Sciences, the Polish Physical Society, and many others, and was a member or fellow of the academies of science in the United States, United Kingdom, India, and Sweden. His nonscientific interests included classical music (especially Mozart), and Shakespeare, and he had a modest repertoire of light verse, brought out only on special occasions.

Roy H. Garstang

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Chang Heng

➔ **Zhang Heng**

Chant, Clarence Augustus

Born **Markham, (Ontario, Canada), 31 May 1865**
Died **Richmond Hill, Ontario, Canada, 18 November 1956**

Clarence Chant was the most important organizational figure in 20th-century Canadian astronomy, having created the first astronomy department in a Canadian university, founded the largest Canadian observatory, and developed the Royal Astronomical

Society of Canada. The son of Christopher Hull Chant of Somerset, England, and Elizabeth Croft of Markham Township, Ontario, Canada, Chant married Jean Laidlaw; their union produced three children: James, Etta, and Elizabeth.

After high school, Chant taught in rural schools and then entered the University of Toronto, graduating in physics and mathematics in 1890. The following year, he began teaching at the University of Toronto, where he took an MA in 1900. Chant spent a year in the physics department at Harvard University to obtain his Ph.D. in 1901.

After Harvard, Chant returned to the University of Toronto where his interests then shifted from physics to astronomy. By 1904, he created a subdepartment of astrophysics within the physics department that eventually evolved into the Department of Astronomy.

From 1912, Chant vigorously pursued the idea of building a university observatory. By the late 1920s, he obtained private funding from the Dunlap family, allowing for the construction of the David Dunlap Observatory. When it opened in 1935, its 74-in. reflector was the second largest telescope in the world. Chant retired at the time of its opening.

A key founder of the Royal Astronomical Society of Canada [RASC], Chant served as its president, established its *Journal* (1907), and edited it for 50 years. He also created the RASC's *Observer's Handbook*. Chant served as a vice-president of the American Astronomical Society and was elected a fellow of the Royal Society of Canada.

Chant's research output was relatively small, although his eclipse photographs in 1922 helped to confirm the gravitational bending of starlight by the Sun, predicted by **Albert Einstein's** theory of general relativity. He published a number of textbooks and a very popular astronomy book, *Our Wonderful Universe*. Before World War II, the majority of Canadian astronomers received their initial training from Chant.

Richard A. Jarrell

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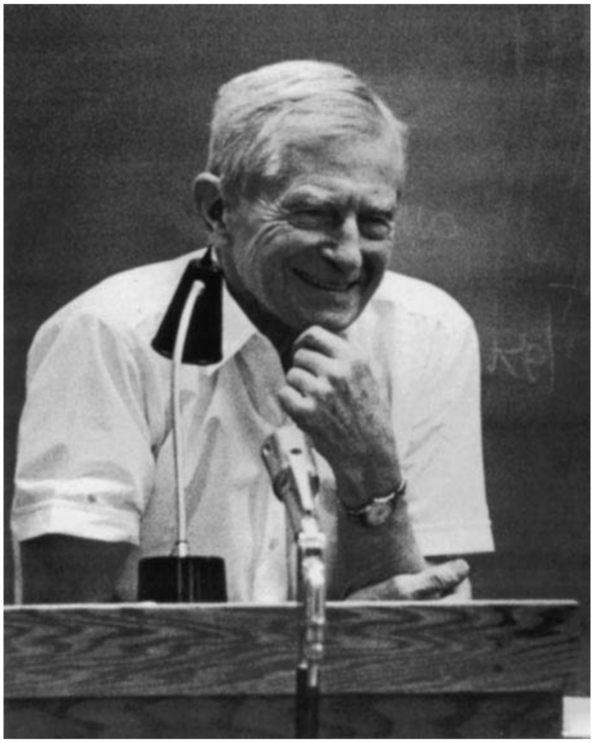
Chapman, Sydney

Born **Eccles near Manchester, England, 29 January 1888**
Died **Boulder, Colorado, USA, 16 June 1970**



British geophysicist Sydney Chapman contributed a number of ideas to the physics of magnetic fields and ionized gases, particularly those of the Earth and of the solar wind interacting with the Earth. He began his advanced education at a technical institute, now the University of Salford, in 1902, going on, under a competitive scholarship, to the University of Manchester in 1904 and receiving his first degree, in engineering, in 1907. Chapman added Manchester B.Sc. and M.A. degrees in mathematics before moving on, again under a scholarship, to Trinity College, Cambridge. Although he could not receive his mathematics degree until 1911, he had completed the examinations in 1910 and accepted a position as one of the chief assistants at the Greenwich Observatory under **Frank Dyson**. The other chief assistant was **Arthur Eddington**. Chapman's first published paper, in 1910, dealt with kinetic theory of gases, which he had taken up at the urging of **Joseph Larmor**.

At Greenwich Observatory, Chapman established a station for regular measurements of the Earth's magnetic field, and geomagnetism, to which he gave its name, remained one of his major fields of activity throughout his life. Appointed to a fellowship at Trinity College and a lectureship in mathematics at Cambridge University in 1914, Chapman was regarded as essential to education and exempted from military service. Something of a pacifist, he did, however, return to Greenwich Observatory and its vital timekeeping and other activities in 1916–1918 as a replacement for **Harold Spencer Jones** who was serving the country. By the time of World War II, Chapman's attitude had changed, and he served as a scientific advisor first to the Ministry of Home Security (1942/1943) and then to the Army Council (1943–1945).

Soon after returning to Cambridge, where some of his work had already made clear the importance of convection and diffusion in transporting both material and heat in stars, Chapman was appointed professor of mathematics at the University of Manchester (1919) as successor to Horace Lamb, who had been his own advisor there. He married Katherine Nora Steinthal, daughter of the treasurer of the university in 1922; she died in 1967, and their four children survived him. While at the University of Manchester, Chapman had apparently shown that the magnetic field of the Sun could influence only its very near environment. This was proven to be incorrect by **Thomas Cowling**, and after Chapman was elected to the chief professorship of mathematics at Imperial College, London, in 1924, one of his first actions was to hire Cowling there. Another of his important London appointments was of **William McCrea**. Chapman's first student (Ph.D.: 1931) there was **Vincenzo Ferraro**. Together they developed the first theory of how a wind from the Sun, ionized but electrically neutral, would interact with the Earth's magnetic field. Another collaboration during this period, with **Edward Milne**, demonstrated that the Earth's upper atmosphere was not chemically homogeneous and that charged particles would penetrate down into it, producing aurorae. A series of papers by Chapman and Ferraro in the early 1930s showed that what is now called the solar wind would form a comet-shaped cavity around the Earth when it impacted the terrestrial magnetic field. This is now called the magnetosphere and is the subject matter of a significant part of space physics.

Part of the Earth's magnetic response to charged flow from the Sun occurs in the atmosphere, but, as **Arthur Schuster** had first suggested in 1889, more important is the induction of currents and fields in the ground and ocean. Chapman and **Alfred Whitehead** (who had been his predecessor at Imperial College) worked out the beginnings of the theory of those processes in 1923. An extension won Chapman the 1929 Adams Prize from Cambridge University, a condition of which was publication of a book. The book finally appeared as a collaboration with his old friend Julius Bartels of Göttingen in 1940, under the title *Geomagnetism* (Oxford: Clarendon Press). They had to exchange proofs through Switzerland, owing to the outbreak of World War II (and the process suggests that Chapman was still not entirely committed to war efforts).

In 1946, Chapman succeeded A. E. H. Love as Sedlian Professor of Natural Philosophy at Oxford University. Among the topics he tackled there was the response of the Earth's atmosphere to day/night changes in the gravitational and heating effects of the Sun and Moon. Chapman showed that an important factor was the absorption of sunlight by ozone, carbon dioxide, and water vapor very high in the atmosphere. This raises and lowers the upper-atmosphere layers, contributing to drag on satellites and the decay of their orbits. Another of his very important contributions over the years was the recognition that the upper atmosphere must have a layer of permanent ionization about 100 km up. This is now recognized as the lowest layer of the ionosphere.

Chapman reached retirement age at Oxford University in 1953 but immediately moved on first, to spearheading, as president of the Special Committee (1953–1959) for the International Geophysical Year, the coordination of a wide range of scientific activities to be carried out during the 1957/1958 maximum of the solar-activity cycle, and, second, to shared research and advisory positions at the High Altitude Observatory in Boulder, Colorado, USA, and the Geophysical Institute at the University of Alaska. With the last of his students there, Syun-Ichi Akasfu, he completed more than 25 joint papers dealing particularly with polar and auroral substorms and a book on *Solar-Terrestrial Physics*. His last book, summarizing the work of many years on *Atmospheric Tides,* appeared jointly with R. S. Lundzen in 1970. A final major review of *The Earth*, prepared for the 150th anniversary of the Royal Astronomical Society, was published after Chapman's death.

Chapman held major offices in, and received prizes and medals from, the Royal Society, the Royal Astronomical Society, the London Mathematics Society, the Royal Meteorological Society, and the Physical Society (all United Kingdom), and is said to have declined a knighthood. He was a foreign or honorary member of the United States National Academy of Sciences and scientific academies in six other countries. Chapman received a total of seven honorary doctorates.

Virginia Trimble

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Chappe d'Auteroche, Jean-Baptiste

Born **Mauriac, (Cantal), France, 23 March 1728**
Died **San José del Cabo, Mexico, 1 August 1769**

L' Abbé Jean-Baptiste Chappe, who has been called "A Pathfinder for Astronomy," is known for his strenuous efforts to observe the transits of Venus in 1761 and 1769. He was the son of Jean Chappe, Baron d'Auteroche, and as a child showed great aptitude for mathematics and for drawing plans.

Jean-Baptiste was educated at the Jesuit college at Mauriac, and later attended the Collège de Louis-le-Grand in Paris, where the Cartesian Dom Germain encouraged Chappe's interests and inspired his passion for astronomy. Having been introduced to **Jacques Cassini** (then director of the Paris Observatory in all but name) by Père de la Tour, principal of the college, Chappe was instructed to draw up plans of the royal palaces and to assist with the *Carte de France*. It was also at Cassini's suggestion that he translated into French part of **Edmond Halley**'s recently published tables of the Sun and the Moon. (Around this time Chappe took orders, and is usually referred to as l'Abbé Chappe in the literature.)

In company with **César Cassini de Thury**, **Giocomo Maraldi**, and **Guillaume le Gentil**, Chappe observed the transit of Mercury of 6 May 1753 at the Paris Observatory. That same year he was appointed by Royal command to survey the county of Bitche in Lorraine where, with the aid of a telescopic quadrant of 3-ft. radius, he determined the latitude of Bitche. With the telescope, he also observed occultations of stars and lunar eclipses to obtain the longitude of the place.

In January 1759, Chappe was elected *adjoint astronome* of the Académie des sciences in succession to **Joseph de Lalande**, who was promoted to be *associate,* and a year later he observed two comets and determined their orbits. In June of that year, Chappe observed an eclipse of the Sun, and in the succeeding year (1761) led a French party to Tobolsk, Siberia, to observe the passage of Venus across the face of the Sun. The event was successfully observed; Chappe remarked about a luminous appendage to the planet at the two internal contacts.

Chappe's monumental three-volume record of the expedition, *Voyage en Sibérie*, also includes observations on Russia and its climate, natural resources, flora and fauna, progress in the arts and sciences, and social customs. Among the many specimens he brought back were portions of what Chappe initially took to be elephant tusks, but in reality were from a mammoth.

Chappe made observations on lightning just at the time its true character was being established. Another mid-century preoccupation in which he was involved focused on the accurate determination of longitude at sea, and in 1764 we find him on board a French corvette off the port of Brest engaged in trials of a new marine chronometer.

Meanwhile, Chappe resumed his astronomical activities at the Paris Observatory and made numerous observations including a meridian observation of Mercury in full daylight in May 1764. By this time plans were afoot to observe the Venus transit of 1769, a spectacle that would not be repeated for over a century. The event could be covered from Europe, but it was thought complementary observations ought to be made from the Pacific Ocean.

Chappe undertook to make the journey and on 18 September 1768 set out, in what was to be the last phase of his career, for the southern extremity of California where near Cape San Lucas the transit could be well observed. On 3 June Chappe made a complete observation of the event. He saw no luminous appendage as in 1761 but did see the "black drop," an elongation of the planet's disk toward the edge or limb of the Sun at ingress and egress.

Unfortunately, the area was in the grip of a virulent epidemic. A few days after the transit, Chappe was struck down along with other members of the party. He recovered, but decided to stay on to observe an eclipse of the Moon due on 18 June. He made the observations but suffered a relapse and died. "His courage and endurance were unbounded," commended his eulogist, Grandjean de Fouchy.

Chappe's papers were taken back to France by surviving members of the expedition. They were edited by **Jean Cassini** and published in 1772.

Richard Baum

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Charlier, Carl Vilhelm Ludvig

Born **Östersund, Sweden, 1 April 1862**
Died **Lund, Sweden, 5 November 1934**

Carl Charlier accelerated the development of statistical astronomy through his application of factory-type data processing at the Lund Observatory. An international figure in astronomy, he influenced outlooks in both the Swedish astronomical community and the International Astronomical Union [IAU] regarding the need for broad international cooperation in science. Charlier also introduced statistical methods to governmental processes in Sweden. He advocated a fractal or hierarchical distribution of galaxies at a time when many astronomers doubted their very existence.

Charlier was the son of Emmerich Emanuel and Aurora Kristina (*née* Hollstein) Charlier. He received his early education in Östersund. Charlier completed his undergraduate education at Uppsala before studying astronomy under Herman Schultz at the University of Uppsala, where he received his Ph.D. in 1887.

Charlier became active in astronomy at a time when photography was entering astronomical practice and celestial mechanics continued to be an important part of theoretical astronomy. He worked in both of these fields during the first part of his career. After completion of his graduate training, Charlier accepted a post as assistant astronomer at the Stockholm Observatory in 1888, remaining there for 2 years. In 1890, he returned to the University of Uppsala, where he served as assistant professor of astronomy at Uppsala Observatory until 1897. Over this decade, Charlier analyzed the principles of photographic photometry, attacked the three-body problem, studied the stability of the Solar System, and tried to find classical solutions to the advance of Mercury's perihelion. Before switching from celestial mechanics to stellar astronomy he published the advanced textbook *Die Mechanik des Himmels*.

In 1897, Charlier was promoted to professor of astronomy at Lund University, and it was here that he made his main contribution to astronomy in stellar statistics. This was the time of an increased division of labor within astronomy that has been described by historians as a period of industrialization of data gathering and analysis. As the amount of photometric, spectroscopic, and astrometric data increased, several astronomers specialized in the statistical treatment of these large bodies of data. Charlier made stellar statistics the dominant mode of astronomical practice at the Lund Observatory, where he and his pupils analyzed large data sets such as the spectral classification data from Harvard College Observatory and photographic sky surveys such as the Franklin – Adams charts. Charlier organized the work at the observatory as a hierarchy, in which female computers, using calculating machines, did the handling of numbers according to methods devised by Charlier and his fellow astronomers. The models of the stellar system of the Lund school were akin to the ones proposed by other statistical astronomers, with the Sun placed quite close to the center of a system that was on the order of 3,000 light years in diameter. When analyzing radial-velocity and proper-motion data, Charlier joined **Karl Schwarzschild** in criticizing **Jacobus Kapteyn**'s work on star streaming; they claimed that the stellar motions could be accounted for without Kapteyn's idea of one distinct star stream moving through another.

Charlier wanted to replicate the Lund model of statistical practice on a larger scale, as an international institute for theoretical astronomy. This way of doing astronomy was outlined by Charlier in his *A Plan for an Institute for Theoretical Astronomical Research*, where he argued for the possibility of doing theoretical astronomy in a way that he claimed was more rational than hitherto. Just as he had begun to mobilize support from the international astronomical community and large-scale funding, World War I erupted and made such an international institute impossible.

Charlier also studied the large-scale structure of the cosmos. In 1908, he argued that the majority of nebulae were stellar systems external to the Milky Way system, strewn out in an infinite Universe. If the nebulae were distributed hierarchically, the paradoxes identified by **Heinrich Olbers** and **Hugo von Seeliger** would, according to Charlier's calculations, disappear, thus countering two objections that had been made to the idea of an infinite Universe. The fact that the nebulae seemed to avoid the Milky Way in the sky had been used as an argument against the nebulae being galaxies. Instead, in 1922 Charlier explained this as an effect of obscuring interstellar matter in the Milky Way system, an idea that several astronomers had been working on during this period.

Charlier was active at a time when Swedish astronomy became more oriented toward the West. Astronomers of the small country on the northern periphery of Europe began to do postdoctoral studies in the United States instead of Germany or Russia, and increasingly they published in English. Charlier took part in this reorientation. He dedicated the first volume of his *Studies in Stellar Astronomy* to **Edward Pickering**, and he argued for electing Pickering as a foreign member of The Royal Swedish Academy of Science. Charlier began making plans for a visit after the war to Harvard, Lick Observatory, Mount Wilson, and Albany because he envisioned collaboration between observational astronomers in the United States and theoretical astronomers in Sweden. During his travels in the United States, Charlier also lectured at the University of California. During the interwar years, several Swedish astronomers, such as **Knut Lundmark**, **Bertil Lindblad**, **Carl Schalén**, **Yngve Öhman**, **Gustaf Strömberg**, and **Erik Holmberg** spent time at American observatories. Most returned to Sweden. However positive toward collaboration with United States astronomy Charlier was, he was also critical of the exclusion of German scientists in the new scientific organizations, such as the IAU, that were launched after the war.

Charlier's political views were radical. He had publicly criticized the role played by the church in Swedish culture in the 1890s. This background made for a politically colored fight in the press surrounding his application for the Lund chair in astronomy of Luna University in 1895. Charlier's idea was that science should be the basis for a more rational organization of the state. Therefore, he lent his statistical expertise to the Swedish state in several state committees dealing with questions such as the possible effects on morality and economics of the introduction of a national lottery, the pricing of railway tickets, construction of pension schemes, and in many other areas.

Charlier's importance extends beyond astronomy. Several of his pupils, for example, **Gunnar Malmquist**, became leading figures in the Swedish astronomical community. Some also became statisticians. Charlier argued for the need for statistical education and research. His cosmological models were soon superseded, but his work in modernizing data handling and statistical methods was an important contribution to astronomy and other parts of modern Swedish society.

In 1897, Charlier married Siri Dorotea Leissner from Stockholm. He was elected to membership in the Royal Swedish Academy of Sciences, Stockholm, in 1898. Charlier was member of the board of the Astronomische Gesellschaft 1904–1923 and active in IAU Commission 33. He received the Watson Medal of the National Academy of Sciences, Washington, in 1924, and the Bruce Gold Medal of the Astronomical Society of the Pacific in 1933.

Charlier's papers are at the Lund University library.

Gustav Holmberg

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Charlois, Auguste

Born **La Cadière, Var, France, 26 November 1864**
Died **Nice, France, 26 March 1910**

French astronomer Auguste Charlois codiscovered minor planet (433) Eros (with **Gustav Witt**) in 1898. Charlois was one shy of his hundredth asteroid discovery when he was murdered.

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Chaucer, Geoffrey

Born **London, England, *circa* 1340**
Died **London, England, 25 October1400**

Poet Geoffrey Chaucer was the son of a prosperous wine merchant. Our earliest records, dating from 1357, show him as a page in a royal household and later a soldier and prisoner of war in the Hundred Years War. He possibly studied law at the Inns of Court. Nothing else is known of his education, although his works show that he was deeply learned in a wide variety of subjects, including astronomy. By the early 1370s he had begun a career in government, in various positions such as a diplomat, tax auditor, member of parliament, manager of royal properties, and finally, deputy forester.

Some of these appointments, certainly the last, might have been more or less honorary, because he was already a practicing poet by the late 1360s, writing first for Richard II's uncle, John of Gaunt, and then for Richard II himself. Always a cosmopolitan and international poet, Chaucer began imitating French models, then came under the influence of the new Italian poetry of **Dante Alighieri**, Petrarch, and Boccaccio, and finally developed a distinctively English style in his most famous work, the incomplete *Canterbury Tales*.

His poetry always displayed a keen interest in astronomy, and in 1391, Chaucer wrote *A Treatise on the Astrolabe* for his young son, Lewis. *The Equatorie of the Planetis*, written in the following year, has sometimes been attributed to Chaucer as well.

In Chaucer's *Miller's Tale*, John the Carpenter refers to a traditional story of an astronomer who watches the skies so intently as he walks along that he falls into a pit. But Chaucer himself always seems to have had his eyes on the sky. In the 14th century, any educated person would have been more familiar with practical astronomy than a person today, because he or she depended on the heavens to determine both the time of day and the date. Although, as a poet rather than a scientist, Chaucer made no direct contribution to astronomy, his work is the best reflection we have of the medieval layman's dependence on and knowledge of things astronomical.

Modern readers tend to think of Chaucer mainly as a satirist. But he was also a serious intellectual with a voracious appetite for knowledge, and his stories are full of specific and sometimes arcane references to cosmic phenomena. Probably following the example of Dante and Boccaccio, he was the first English poet to make frequent use of astronomical periphrasis (according to the Ptolemaic System) to specify time in his stories.

It is necessary to point out that astrology and astronomy seem inseparable to the medieval mind. Even in his scientific *Treatise on the Astrolabe*, the fifth section, which Chaucer planned but never wrote, was to be devoted to astrology. But *Astrolabe* also proves that medieval thinkers did not necessarily accept pseudo-science blindly. Although all his fictional characters accept without question that astrology determines personality traits and life events, Chaucer says unequivocally in *Astrolabe* that he does not believe in "judicial astrology" (horoscopes) and the unchristian notion of fate that it implies. He accepts astrology as a literary device, but his interest in astronomy is real.

That Chaucer had both an intellectual and a practical interest in science for its own sake is made clear in *Astrolabe*. The astrolabe was the simplest of medieval devices for calculating date and time by the positions of the planets and vice versa. Chaucer's instructional manual is elementary also because he is writing it for his son, "little Lewis," who was probably about 10 when the treatise was written in 1391. Nevertheless, Chaucer devoted the same energy and attention to this technical subject as he did to the study of philosophy, law, medicine, and even alchemy for literary purposes. We do not know how or when he gained his knowledge of astronomy. He certainly was familiar with the standard textbook of the Ptolemaic system, *De Sphaera*, written by the 13th-century Englishman **John of Holywood**. Moreover, Chaucer had connections to Merton College, Oxford, which was the center of astronomical study in 14th-century England.

Chaucer's own *A Treatise on the Astrolabe* is significant to the history of astronomy because it seems to be the oldest work in the English language on a scientific instrument (although this assertion has been challenged). His prose is a model of clear technical writing. Chaucer says in his introduction that he planned five systematic sections for the *Astrolabe*, although he completed only the first two. Section 1 is a description of the astrolabe's parts. Section 2 is a set of 40 astronomical practice problems, some of which appear to be original with Chaucer, others borrowed from a Latin translation of a work by the 8th-century astronomer **Māshā Allah** (which is his most important source for the treatise). The next two sections were to be tables of planetary positions in relation to major cities and in relation to the Moon, and the fifth, as already stated, was to be about astrology.

Like *Astrolabe, Equatorie of the Planetis* is unfinished, and although Chaucer's authorship of it is disputed, it is worth noting that the mathematical calculations in it could have been used to create the tables that were planned for parts 3 and 4 of the earlier treatise. An equatorie was a more complex instrument than an astrolabe, used to calculate the positions of the planets in relation to each other, and the author of *Equatorie* demonstrates sophisticated mathematical skills. Prevailing scholarly opinion at the moment is that Chaucer is not the author. Nevertheless, *Equatorie* is important as a source of the kind of astronomical knowledge that was available to Chaucer and other 14th-century intellectuals.

Ultimately, though, it is in his poetry rather than in his prose that we see the depth of Chaucer's interest in astronomy. Chaucer devotes such close attention to the technical knowledge of astrology and pure astronomy, and to their artful use, that he must have thought of them as more than just conventional rhetorical devices. They must have been a way for the poet to capture in the precision of his language the beauty of the precision in science.

Alan Baragona

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Chauvenet, William

Born **Milford, Pennsylvania, USA, 24 May 1820**
Died **Saint Paul, Minnesota, USA, 13 December 1870**

William Chauvenet, who was instrumental in founding the United States Naval Academy and later served as chancellor of Washington University, introduced many American students to astronomy, mathematics, and navigation through his widely used textbooks and journal articles.

Chauvenet's father, William Marc Chauvenet, who was born in Narbonne, France, in 1790, left France after the defeat of Napoleon to come to the United States, where he met and married the former Mary B. Kerr of Boston. They briefly farmed near Milford, Pennsylvania, where William was born. The family moved to Philadelphia in 1821. After receiving his preparatory education there, Chauvenet attended Yale University from 1836 to 1840, studying mathematics and classics, and graduating with high honors. Chauvenet worked briefly for **Alexander Bache** making magnetic observations at the Gerard College Observatory before accepting, in 1841, an appointment as professor of mathematics in the US Navy. Because of requirements of the time, Chauvenet served for a few months aboard the steamer *USS Mississippi*. In 1842 he became head of the Naval Asylum, a shore-based school for naval officers in Philadelphia. Chauvenet convinced Naval Secretary George Bancroft and the US Congress to move the school to Annapolis, Maryland, in 1845 and reestablish it there as the US Naval Academy [USNA]. In 1851, the USNA course of study was expanded from its former duration of only 8 months to 4 years that would precede sea service.

At the Naval Academy, Chauvenet served first as a professor of mathematics and astronomy, and later of astronomy, navigation, and surveying. During his tenure there, he refused professorships in mathematics and in astronomy and natural philosophy at Yale University. In 1859 Chauvenet left the Naval Academy to become chair of the Mathematics Department at Washington University in Saint Louis. Three years later he became chancellor of Washington University. After a long illness, Chauvenet died.

Chauvenet's three texts on astronomy, mathematics, and navigation were widely used by American students and remained in print well into the 20th century. He also published 15 journal articles primarily on navigation and spherical trigonometry. Chauvenet invented the great circle protractor that navigators use to find great circle routes much like Mercator projections aid in finding rhumb line routes.

Chauvenet was elected president of the American Association for the Advancement of Science and vice president of the National Academy of Science. In 1925, the Mathematical Association of America established the annual Chauvenet Prize for the best expository mathematical article. Chauvenet Hall at USNA is named in his honor. Built in 1969, renovated in 2005–2006, it currently houses the academy's mathematics, oceanography, and physics departments.

Mark D. Meyerson

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Chemla-Lameche, Felix

Born **Tunesia, 1894**
Died **1962**

Greek–French selenographer Felix Lameche was one of the last pre-photographic observers to have his lunar place names come into general use.

Alternate name

Lamech, Felix

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Ch'en Cho

Chen Zhuo

Chen Kui

Flourished **China, 16th century**

Ming Dynasty's Chen Kui published a polar-projection star chart containing 283 asterisms and 1,464 stars.

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Chen Meidong (1997). "A Preliminary Study of Two Star Charts from the Early Ming Dynasty of China." In *Oriental Astronomy from Guo Shoujing to King Sejong*, edited by I.-S. Nha and F. Richard Stephenson, p. 238. Seoul: Yonsei University Press.

Chen Zhuo

Flourished **China, *circa* 265–317**

Chen Zhuo produced important surveys of the skies in his role as a Chinese astronomer in the Wu dynasty of the Sanguo (Three Kingdoms) period (220–265) and subsequent western Jìn dynasty (265–316). Chen Zhuo was *Taishiling* (Director of the Imperial Bureau of Astronomy and Calendrics) in Wu. After the Wu dynasty was defeated by the western Jìn dynasty in 280, he was again appointed *Taishiling*.

During the Sanguo period, studies in Chinese classical astronomy, which had started in the Han dynasty, continued to develop. The Three Kingdoms were Wei (220–265), Shu (221–263), and Wu (222–280). From 223, the Wu dynasty officially used the Qianxiang calendar compiled in 206 by Liu Hong. In the Wei dynasty, the Jingchu calendar of Yang Wei was used from 237. With it, the basis of the standard system of the prediction of solar and lunar eclipses was established. Then, in the Wu dynasty, Chen Zhuo established the standard system of Chinese constellations.

Systematization of Chinese constellations begins with the 28 lunar mansions (*xiu*). In 1978, a lacquer box on which the name of each lunar mansion is written was excavated from a tomb (dated to 433 BCE) in Hebei province showing that the complete system of lunar mansions already existed by the late 5th century BCE. The first Chinese text in which constellations are described is the "Treatise on the Heavenly Offices" in the *Shiji* (The Grand Scribe's Records, *circa* 91 BCE) by **Sima Qian**. Here, over 90 constellations comprising more than 500 stars are described.

Subsequently, Chen Zhuo made his own comprehensive survey of stars and recorded 283 constellations with 1,465 (or 1,464) stars. Constellations other than lunar mansions were divided into three groups and were attributed to three ancient quasi-legendary astronomers, **Gan De** and **Shi Shen** of the Warring States period and Wu Xian of the Shang (= Yin) dynasty (mid-16th century to 1046 BCE).

Although Chen Zhuo's own work is not extant, his system of constellations became the standard system of Chinese traditional constellations, and is known from later works that were based on Chen Zhuo's system, such as the poetic *Butiange* (Pacing the Heavens). The authorship of this poem is controversial; some attribute it to Dan Yuanzi of the Sui dynasty (581–618) and some to Wang Ximing of the Tang dynasty (618–907). (Some people suspect that they are the same person.)

Mention may be made here of Chinese star maps, which are also based on Chen Zhuo's system. Besides the celestial globe, there were two types of star map projections used. One type is a single round map whose center is the North Celestial Pole. An example of this type is the famous star map inscribed in stone from Suzhou (in Jiangsu Province), carved in 1247. Another type is a set containing a round map showing circumpolar stars and a rectangular map centered on the Celestial Equator. An example of this type is the printed star map in the *Xin yixiang fayao* (Outline of the method for a new instrument) by **Su Song**.

Alternate name

Ch' en Cho

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Chiaramonti, Scipione

Born **Cesena, (Emilia-Romagna, Italy), 1565**
Died **Cesena, (Emilia-Romagna, Italy), 1652**

Scipione Chiaramonti's astronomical writings – *Discorso della cometa … dell'anno MDCXVIII …* (Venice, 1619), *Antitycho* (Venice, 1621), and *De tribus novis stellis quae 1572, 1600, 1604 …* (Cesena,

1628) – were devoted to maintaining the argument of the sublunary character of comets and novae.

Chiaramonti studied in Ferrara and was professor of philosophy in Pisa from 1627 to 1636, but he spent the major part of his life in Cesena, a town under the temporal power of the Catholic Church. The range of his activity embraced both scientific and humanistic fields. He wrote books to support Aristotelian ideas and took part in hard polemics against Copernicans, such as **Johannes Kepler** and **Galileo Galilei**, and Tychonic supporters, such as Father **Orazio Grassi**.

Chiamonti's first work, which turned against Grassi's theory of comets, was welcomed by Galilei. However, Chiaramonti was harshly attacked by Kepler in 1625 and by Galilei himself in the *Dialogo sopra i due massimi sistemi del mondo* because of his arguments against the motion of the Earth and his interpretation of the novae. Chiaramonti's ideas, cited many times by Simplicio in the *Dialogo*, rendered Chiaramonti an easy target for Galilean criticisms.

Davide Neri

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Chioniades, Gregor [George]

Born **Constantinople (Istanbul, Turkey), *circa* 1240**
Died **Trebizond (Trabzon, Turkey), *circa* 1320**

Born in Constantinople and christened George, Chioniades became a physician. Greatly attracted to mathematics, astronomy, and medical astrology, he chose to travel to Persia to further his studies. Early in 1295, he went to Trebizond (Trapezus) where he found favor with the emperor of Trebizond John II Komnenos (reigned: 1280–1297), who supported his travel and study in Persia. Between November 1295 and November 1296 he was received at the court of the Mongol Īlkhāns at Tabrīz where he studied astronomy and astrology with **Shams al-Dīn al-Bukhārī**, an astronomer and teacher from Bukhārā in Central Asia. Shams al-Dīn was the author of a Persian treatise on the astrolabe that Chioniades later translated into Greek.

During his stay in Tabrīz, Chioniades amassed an important collection of astronomical works in Persian and Arabic that he took with him on his return to Trebizond and later to Constantinople. Some of these works he translated into Greek, adding commentaries and incorporating his own notes written in Greek, Persian, and Arabic from his studies with Shams al-Dīn. Chioniades founded schools for the study of astronomy and medical astrology in both Trebizond and Constantinople.

By September 1301 Chioniades had returned to Trebizond, and by April 1302 he was in Constantinople. He translated into Greek a set of recipes for antidotes and wrote a confession of faith to refute suspicions of heresy based on his work in astrology and his sojourn with the Persians. In 1305, appointed Bishop of Tabrīz, Chioniades took the name Gregory. He remained in Tabrīz until about 1310, retiring for his final years as a monk to Trebizond. Chioniades left part of his library to Constantine Loukites. His translations from Persian into Greek assisted in the transmission of this material to the medieval and Renaissance worlds of the west.

Chioniades' work associated with astronomy includes his translations of several astronomical works from Persian or Arabic into Greek, including the *Zīj al-ˁAlāʾī* (The Alai astronomical handbook with tables), the *Persian Astronomical Composition*, and the *Revised Canons*. Translations of two astronomical tables, **Khāzinī**'s *Sanjarī Zīj* and **Ṭūsī**'s *Īlkhānī Zīj*, are also considered to be by Chioniades. He translated the work on the astrolabe written by Shams al-Dīn and wrote a short introduction to astronomy, *The Schemata of the Stars*. His translations and body of work provide evidence that Byzantine astronomers preserved scientific ideas from **Ptolemy** and Islamic scientists and further added their own contributions, making observations and refining existing cosmological models. Chioniades' introduction to astronomy includes diagrams of the models based on the Ṭūsī couple, which refined current cosmological theory and which was used by **Nicholas Copernicus** in his work on the heliocentric Solar System.

Katherine Haramundanis

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Westerink, L. G. (1980). "La profession de foi de Gregoire Chioniades." *Revue des études byzantines* 38: 233–245.

Chladni, Ernst Florens Friedrich

Born **Wittenberg, (Germany), 30 November 1756**
Died **Breslau (Wrocław, Poland), 3 April 1827**

Ernst Chladni contributed significantly to the founding of modern meteoritics. He was the only child of Ernst Martin and Johanna Sophia Chladni. The family was originally from Kremnitz (Kremnica), Slovakia. Chladni's grandfather and father were both professors of jurisprudence at Wittenberg. He never married.

Although he was educated by his parents in a strict, rather isolated household, Chladni developed a yearning for travel and a strong interest in the natural history of the Earth and the heavens. On his father's bidding, Chladni studied law and philosophy at Wittenberg and Leipzig, where he earned his doctorate in 1782. His father died shortly afterward, leaving him free to pursue his own interests.

Chladni mastered mathematics and physics and conducted his earliest experiments on the vibrations of solid plates and the velocity

of sound waves in various gases. He also designed and built two keyboard musical instruments, the euphonium and the clavicylinder. In 1787, Chladni published a highly influential book on the theory of sound waves for which he became known as the "father of acoustics." He then began a lifetime of traveling, giving lectures and demonstrations, first on acoustics and later on meteorites, between periods of working and writing at home in Wittenberg.

In the early 1790s, Chladni's became interested in the nature of fireballs. He questioned whether they form around solid bodies as they plunge through the atmosphere or consist entirely of gases. Chladni spent 3 weeks at the library in Göttingen where he discovered that eyewitnesses in different centuries and in widely spaced localities had given remarkably similar accounts in sworn testimony to the appearances of brilliant fireballs accompanied by thunderous explosions and followed by the fall of stones or fragments of iron out of the sky.

Contemporary scholars viewed the idea of rocks from the sky as vulgar superstition. But Chladni selected the 18 most detailed fireball reports from those dating between 1676 and 1783 and compared their apparent beginning and end points, magnitudes, velocities, and the number and force of their explosions. His results were so consistent, and the eyewitness testimony so convincing to his lawyer's ear, that Chladni concluded that solid bodies falling from fireballs are authentic natural phenomena.

Other scientists explained fireballs as atmospheric phenomena, related in some way to either electricity, the zodiacal light, the aurora, or to streaks of inflammable gases in the sky. Noting that fireball velocities greatly exceeded those attributable to gravity, Chladni perceived that they could not originate in the atmosphere but must enter the upper atmosphere from space and then heat to incandescence as they decelerate due to friction with the air. He explained meteors the same way except that he believed that these small bodies pass through the atmosphere and reenter space instead of burning up. Chladni proposed that the incoming bodies are small masses of primordial matter that formed in deep space and never accumulated into planets, or are the debris of planets that have been destroyed by internal explosions or by collisions in space.

In comparing descriptions of the allegedly fallen stones, Chladni found that they all had thin black crusts wholly or partially covering gray interiors sprinkled with small grains of shiny metal. At least one body, observed to fall from a fireball in 1751 at Hraschina in Croatia, was a 71-lb mass of metallic iron. Chladni reasoned that if this piece of metal fell from the sky, so did two other isolated iron masses, one of which had been found in the remote chacos of northern Argentina, the other on a mountainside in Siberia. Each of these lay far from volcanoes or any mining or smelting operations. The Siberian iron had been shipped to Saint Petersburg by Peter Simon Pallas. It consisted of metallic iron studded with large, translucent yellow crystals, which Chladni correctly surmised were olivine. Similar meteorites came to be called pallasites.

In 1794, before he ever examined a meteorite, Chladni published a small book, *Über der Ursprung der von Pallas Gefundenen und anderer ihr ähnlicher Eisenmassen, und Über Einige Damit in Verbindung stehende Naturerscheinungen*, in which he compiled all his data, demolished other hypotheses case by case, and presented his conclusions: (1) solid bodies of stone and iron do, in fact, fall from the sky; (2) they form fireballs as they plunge through the atmosphere; and (3) they originate in space. This was the first scholarly book on meteorites, and it applied the principles of physics to them. Although Chladni made some serious errors in it, his basic conclusions were sound. Nevertheless, his book was not well received. Scholars refused to trust the testimony of uneducated people and responded to reports of fallen bodies by identifying the specimens as ordinary rocks struck by lightning, fragments hurled from distant volcanoes, or masses coagulated from dust in the atmosphere – a process that had been suggested in 1789 by the chemist Antoine-Laurent de Lavoisier. More seriously, Chladni's book violated some of the deepest-held convictions about the nature of the Universe. Chladni's hypothesis that small bodies originate in space ran counter to **Isaac Newton**'s dictum of 1704 that to assure the regular and lasting motions of his clockwork Solar System, based on his laws of universal gravitation, all space beyond the Moon must be empty.

Between 1794 and 1798, falls of stone occurred in Italy, England, Portugal, and India. These events prompted Sir Joseph Banks, the president of the Royal Society in London, to ask chemist Edward C. Howard to analyze some of the stones. Howard, working with the mineralogist Jacques-Louis de Bournon, analyzed four fallen stones and four suspected fragments of fallen iron. He made the totally unexpected discovery that the irons and the metal grains in the stones all contained several percent of nickel. This linked irons with stones and set both apart from common rocks of the Earth's crust. From this work, published in 1802, in which Howard referred to Chladni's book, meteoritics emerged as a new branch of science.

Chladni's theory of fireballs soon gained acceptance, and he received full credit for it. He obtained specimens for study and published numerous papers on them plus one more book, in which he summarized all that was known about meteorites in 1819. Ultimately, Chladni acquired the largest private meteorite collection of the early 19th century and willed it to the University of Berlin where his specimens are on display. Still, Chladni's theory of the origin of meteorites in space gained little support until the 1860s. Today we accept his suggestion that meteorites are debris from collisions in space. Most of them are fragments of asteroids, and a few result from asteroidal impacts on the Moon and Mars.

Ursula B. Marvin

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Cholgi: Maḥmūd Shāh Cholgi

Flourished **probably 15th century**

Since the colophon of the Persian *Zīj-i jāmiʿ* mentions his name, Cholgi has traditionally been taken as the author/compiler of this collection of astronomical tables. He has been identified with the ruler of Malwah, a state in central India, from 1435 to 1469, making him, like **Ulugh Beg**, both prince and mathematician. Ramsey Wright has suggested, however, that the treatise was not written by the prince himself, but rather was dedicated to him by the still-anonymous author. If the prince did indeed compose this treatise, it appears to be the only work he did in astronomy. A Persian manuscript in the Bodleian Library (*Persian Manuscript Catalog*, number 270) apparently chronicles the events of his reign, but no one seems to have yet examined it for any references to astronomical activity.

The introduction informs us that the treatise originally comprised an introduction (*muqaddima*), two chapters (*bāb*), and a conclusion or appendix (*khātima*). The last chapter and appendix were already lost during the author's lifetime. The introduction has 36 sections (*faṣl*). The first of these sections is the best known because it was published, with facing Latin translation, by **John Greaves** in his *Astronomica quaedam* (London, 1652). This initial section contains basic geometrical definitions, an elementary introduction to Islamic *hay'a* (cosmography and cosmology), and some brief explications of concepts used in spherical astronomy. Sections 2–24 deal with topics from arithmetic and calculations useful for spherical astronomy. Sections 25–36 describe the astrolabe and its use. The work seems to present itself (and is usually cataloged) as a commentary on the *Zīj-i Ilkhānī* of **Naṣīr al-Dīn al-Ṭūsī**. This description seems too presumptuous. It might better be said to represent a considerably simplified prolegomena to Ṭūsī's work (or to mathematical astronomy in general) rather than an explication of its contents.

The most interesting part of this introductory section (and of the *Astronomica quaedam*) is the cosmographical/cosmological model building. There is nothing original from the point of view of astronomical theory or practice. It is essentially a simple recapitulation of the model in **Ptolemy**'s *Planetary Hypotheses* and the nested spheres described by **Ibn al-Haytham**. Although he cites the "new" results of Ṭūsī's work, Cholgi has in mind only the correction of the rate of precession to 1° per 66 years, not Ṭūsī's new, non-Ptolemaic astronomical models.

Gregg DeYoung

Alternate name

Khaljī: Maḥmūd Shāh Khaljī

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Christiansen, Wilbur Norman

Born **Melbourne, Victoria, Australia, 9 August 1913**

Australian radio astronomer W. N. (Chris) Christiansen received his degrees (B.Sc.: 1934; M.Sc.: 1935; and D.Sc.: 1953) from the University of Melbourne. He was part of a group of radar physicists and engineers who, at the end of World War II, turned their attention to radio astronomy as part of the national research coordinating organization, the Commonwealth Science and Industrial Research Organization [CSIRO], under the leadership of E. G. (Taffy) Bowen and **Joseph Pawsey**. The group initially focused on studies of radio emission from the Sun (partly because solar interference had been a major concern in their radar days). In the late 1940s, Christiansen designed an array of 32 parabolic radio dishes to be built in an east–west line along the wall of a reservoir at Potts Hill. The rotation of the Earth carried the line of antennas around at different angles relative to the face of the Sun, so that a sort of map of solar radio emission could be constructed. Later versions of this Earth Rotation Aperture Synthesis generally used movable antennas, so that the base lines could be changed to get different levels of angular resolution, but the principle was established at Potts Hill.

The array was operational by 1951, but work was interrupted by news of the 1951 discovery of the 21-cm emission line of neutral hydrogen (made at Harvard by **Edward Purcell** and Harold Ewen). The Australians confirmed the detection quickly (as did a group in the Netherlands working with **Jan Oort**), and all three announcements were published together. Christiansen and J. V. Hindman then carried out a preliminary survey of the distribution of 21-cm radiation over the sky, finding that the line doubled into two velocity components in some directions, which they associated with the possibility of spiral arms in our Galaxy.

In the 1950s, Christiansen designed and built a new solar array at Fleurs, with antennas along both east–west and north–south arms, which became known as the Chris Cross. He collaborated with Chinese astronomers in designing antennas as part of their first efforts in solar radio astronomy. Christiansen became professor of electrical engineering at the University of Sydney in 1960 and expanded the Chris Cross to a larger array, the Fleurs Synthesis Telescope.

Christiansen served as a vice president of the International Astronomical Union (1964–1970) and president of the International Union of Radio Science [URSI] (1978–1981). He is spending his retirement in a small town not far from the Mount Stromlo Observatory and Canberra.

Philip Edwards

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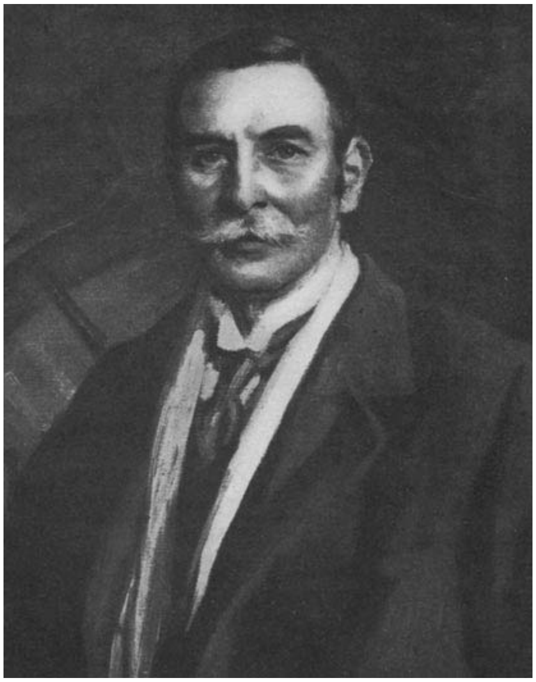
Christie, William Henry Mahoney

Born **Woolwich, England, 1 October 1845**
Died **at sea, en route to Morocco, 22 January 1922**

William Christie, eighth Astronomer Royal of England and director of the Royal Greenwich Observatory, revitalized the observatory after the 46-year tenure of **George Airy** and guided its activities into directions appropriate for a national facility, including British participation in the *Carte du Ciel* project.

Christie was the third son, and the eldest child by a second marriage, of Samuel Hunter Christie, born when S. H. Christie, F.R.S. (fellow of the Royal Society) was professor of mathematics at the Royal Military Academy at Woolwich from 1838 to 1854. The second son, James Robert Christie, also became F.R.S. and was on the staff there. Christie's mother was from an Irish family, from whence came his third given name. Christie was educated at King's College School, London, and entered Trinity College, Cambridge, in 1864. He graduated fourth wrangler (*i. e.*, that place in the first class in mathematics) in 1868 and was soon elected a teaching fellow of the college.

Airy, appointed Astronomer Royal in 1835, selected young men of talent and mathematical ability as chief assistants to superintend the day-to-day staffing and operation of the observatory. He had examined Christie in astronomy at Cambridge in 1866, and when **Edward Stone** was appointed astronomer at the Cape of Good Hope in 1870, Airy selected Christie for the vacant post. Airy was at that time pursuing an interest in lunar theory and may have hoped that Christie would assist him in that also, but in this he was disappointed.



Christie immersed himself in the routine work of positional astronomy, familiarizing himself with the operations of the transit circle and altazimuth, and analyzing, for example, systematic errors in the determination of north polar distances. His personal inclination was, however, to physical astronomy, and Airy did not discourage it; by 1873 Christie had added to the routine of the observatory the study of sunspots by systematic photography of the solar surface, which continued for nearly a century. In the following years, papers on spectroscope design, stellar photometry, a new form of solar eyepiece, and on the nature of the light from Venus, indicate the growth of his interests. He also became active in the affairs of the Royal Astronomical Society [RAS], and in 1877 was encouraged by friends to become the founder editor of a new (and independent) monthly magazine, *The Observatory*, which continues to the present day. Christie served as RAS secretary from 1880 to 1882 and was president from 1888 to 1890.

Airy retired at the age of 80 in 1881. He had not been resistant to change (as is sometimes wrongly supposed) and his tenure had seen the introduction of departments for solar, magnetic, and meteorological observations. The observatory was a department of the Admiralty, which had willingly allowed Airy to develop his own idiosyncratic methods of economical administration that he had altered little over 45 years. The advisors to the Crown appointment recommended Christie as Airy's successor, as one with interests in the new physical astronomy, but, after 10 years on the staff, cognizant of what needed to be changed.

Christie's almost first decision in 1881 was the selection of a chief assistant to fill the post he had just vacated. He temporized, and promoted Edward Dunkin from within the staff, a reward for Dunkin's long service. This was to create future difficulty when Dunkin himself came to retirement 3 years later. The senior staff had seen both Christie and Dunkin promoted from within, and resented the return to the old custom of importing young Cambridge mathematicians; this course was however wise, for it brought into astronomy men with the caliber of **Herbert Turner**, **Frank Dyson**, and **Arthur Eddington**, who might otherwise have turned to other subjects.

Although Christie attended the International Geodetic Association meeting in Rome in 1883, when the proposal for a universal day based on the Greenwich meridian was aired, he felt too committed to Greenwich to attend the determining Washington Conference in 1884, but gave support to the United Kingdom delegates on the issue of establishing time zones.

On the observational side Christie started with major modifications to the collimators of Airy's transit circle, and proceeded to improve the equipment for solar photography and terrestrial magnetism. Christie was not primarily an observer and original investigator, but was well-informed and knew what was needed; he had particular skills in optics and lens design. He turned his attention to the building of the large visual and photographic telescopes that the observatory lacked, and used his talent for gentle persuasion to fund them. The 28-in. refractor was mounted (in an existing dome modified to become the familiar onion shape on the Greenwich skyline) in 1893, and the funding for the Thompson photographic refractor followed in 1894. In the following years a new altazimuth (a universal transit circle) was built, and work proceeded on the new "Physical Observatory" through the 1890s, which became the main building of the observatory. It was a natural step to commit the observatory to a zone of the *Carte du Ciel* (1887–1964), and a distant enclosure and new building were added to the grounds for the determination of absolute magnetic elements, completed in 1898.

By the turn of the century Christie was a widely respected and well-liked director of a greatly enlarged and efficient institution, concentrating still on the branches of astronomy best suited to a national observatory. In his later years his health was not good, and he retired at the age of 65 in 1910, to be succeeded by Dyson. He had been elected fellow of the Royal Society in 1881 and was later appointed to various civil honors, including knighthood in 1904.

In 1881, Christie had married Violette Mary Hickman, who died in 1888. Of the two sons, the younger died in early childhood and the elder became a barrister-at-law. After retiring to the country Christie took winter cruises to warmer climates and, although not apparently seriously ill, died suddenly on a cruise. He was committed to the sea the following day, at latitude 40° 3.5′ N and longitude 9° 20′ W.

Christie's largely unpublished professional papers and correspondence are in the archives of the Royal Greenwich Observatory (Christie Papers) in the Cambridge University Library, and in the archives of the Royal Astronomical Society.

David W. Dewhirst

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Christmann, Jacob

Born **Johannesberg, (Hessen, Germany), November 1554**
Died **Heidelberg, (Germany), 16 June 1613**

Jacob Christmann's scientific work was directed, above all, toward Arabic astronomy and chronology.

Christmann was born in Johannisberg near Mainz and subsequently educated in Neuhausen. In Heidelberg he dedicated himself principally to oriental studies and became a teacher at the Dionysianum there. When in 1579 he refused to sign the Lutheran Concordat, on account of his Calvinist beliefs, Christmann had to leave Heidelberg and went first to Basel, and then to the reformed Gelehrtenschule (classical grammar school) in Neustadt an der Haardt in the Pfaelzer Wald. Following the death of the elector, Christmann was able to return to Heidelberg in 1584, becoming professor of Hebrew language, and in 1591 professor of logic. In 1608 he became the second professor of Arabic in Europe. (The first was in 1538 in Paris.) In the year 1602 Christmann became rector of Heidelberg University. The view, which is often put forward, that he was for a period active in the service of the Landgrave **Wilhelm IV** does not hold.

Christmann's scholarship was a topic for which he was well equipped by his knowledge of Syrian, Chaldean, and Greek, as well as Latin. His aim, by means of new editions and corrected translations of Arabic works, was to make it possible to study Arabic philosophy and astronomy (especially calendrics) from authentic sources. To support this, Christmann had already by 1582 published an introduction to the study of Arabic. His translation of **al-Farghani** appeared in 1590, for which he made use of a Hebrew original: in the appendix he gives comprehensive chronologies, including those of the Romans and of India. He dealt with the Jewish chronology in 1593 in an open letter to J. Lipsius; in the same year he applied himself to the date of Christ's death, and in 1594 returned to the Jewish and Arabic calendars.

Three works are devoted to practical astronomy, along with mathematics, appearing in 1601, 1611, and 1612. With the latter Christmann "acquired a notable place in the history of the technique of astronomical observation" (Ludendorff). He described here for the first time the combined use of sighting instruments together with the telescope for the improvement of observational accuracy. In his *Theoria Lunae* – the dedication of the book is dated 13 April 1613 – he described how he carried out observations using a sextant with a Galilean telescope mounted on its alidade ("Conspiculum") to obtain better sighting of the foresight as well as the observed object. On 18 and 24 December 1611, Christmann used a telescope with sixfold magnification together with a Jacob's staff so that while reckoning the distance between them he was also able to observe both objects more clearly.

Christmann built his telescopes and other instruments himself. He possessed, among others, six telescopes with two- to tenfold magnification, some of these being the so called trumpet-telescopes, with larger ocular and smaller objective lenses. He also used one of the latter, with an object lens of 6-cm diameter, in conjunction with a Jacob's staff. Christmann recorded his unsuccessful attempts to observe the satellites of Jupiter and the shape of Saturn with telescopes with 2-in. apertures. The quality of his lenses, particularly with respect to the sharpness of image, was plainly unsatisfactory. It is an interesting detail of the early history of telescopic observations that Christmann, who was generally at ease with the use of the telescope, rejected the existence of the moons of Jupiter and the "Henkel" (appendages) of Saturn, already noted by several observers, as deception. Christmann is hardly to be blamed for this: It reflects the problem of the early telescopes and their astronomical application.

In 1595 Christmann published a work on the squaring of the circle, in which he stated that the area of the circle can only be approximately equated to the area of a square. In his *Nodus Gordius* he taught the solution of geometrical tasks by sine functions rather than by algebraic means.

Following the death of Valentin Othos in 1603, Christmann came into possession of the original manuscript of **Nicolaus Copernicus**' *De Revolutionibus*, which Otho had previously acquired from **Rheticus**. Christmann was aware of the significance of this acquisition but did not regard the manuscript as a venerable relic; rather he was challenged by it to familiarize himself with the heliocentric theory "ad usum studij mathematici," as he wrote on a flyleaf of this volume.

Jürgen Hamel
Translated by: *Peter Nockolds*

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Chrysippus of Soloi

Born **Soli (near Mersin, Turkey), *circa* 280 BCE**
Died **Athens, (Greece), 207 BCE**

Chrysippus' chief astronomical contribution was his cosmology, which served as the dominant paradigm until the time of astronomer **Ptolemy** (*circa* 150).

Chrysippus was born under the rule of Ptolemy II (the Greek king of Egypt); but his family was Kilikian (a Semitic people), and he learned Greek before he moved (at about 20) to Athens. There he studied philosophy under the Stoic scholarch Kleanthes (the name "Chrys-ippos," meaning "gold-steed," may translate his native name). From 232 BCE until his death, Chrysippus was scholarch of the Stoa, one of the four major schools of philosophy in Athens.

Chrysippus wrote extensively on Stoic philosophy – 90% of all Stoic writings in the third century BCE were by him – covering astronomical topics in such works as *On the Kosmos*, *On Motion*, *On Nature*, and *On the Void* through which he standardized Stoic doctrines. (His writings are now preserved solely in extracts.)

Chrysippus' cosmology held that the *kosmos* is cyclic, "beginning" as fire, which then by successive condensations transmutes in turn to air, then water, then earth, and cycles back again by successive dissolutions; the fire at the end of a cycle is the origin of the following cycle. His *kosmos* possessed two fundamental principles: (1) passive and qualityless matter acted upon by (2) the supreme god who imposes form and function on matter to generate the *kosmos*. Outside the spherical *kosmos* is boundless and uniform void, so that one cannot speak of the *kosmos* as other than central and stationary in the void. During its fiery phase, the *kosmos* expands into (but does not fill) this void. Four elements compose the *kosmos* in spherical shells, fire around air around water around earth, and the *kosmos* maintains its coherence despite their internal motions because they have bounded natural motions and places. (Zenon, the founder of Stoicism, had followed Greek tradition in placing the Earth at the center of the *kosmos*.) Moreover, the *kosmos* is alive, sentient, and even rational (a view derived from **Plato**'s *Timaios*, which Chrysippos supported by recourse to teleological arguments). The *kosmic* center of thought (*hegemonikon*) he placed in the peripheral *aithêr* (a species of fire, according to Chrysippus), and the *kosmic* soul he found in the *pneuma* (a mixture of fire and air) that pervaded the whole *kosmos* and caused the coherence and organic unity of the *kosmos*.

His picture of the structure of the *kosmos* was that the *aithêr* rotates in a spherical shell around the spherical Earth; the *aithêr* is composed of nested spherical shells, the outermost of which contains the innumerable fixed stars. Inside that are found, in order, Saturn, Jupiter, Mars, Mercury, Venus, the Sun, and the Moon. This order, apparently advocated by Plato (in *Republic* 10, *Timaios*, and *Epinomis*), **Aristotle** left to the "mathematicians" (in *On Heaven*) or may have followed (in *Metaphysics*), as did most astronomers in the 4th and 3rd centuries BCE.

Paul T. Keyser

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Chunradus de Monte Puellarum

➲ **Megenberg, Konrad [Conrad] von**

Cicero, Marcus Tullius

Born **Arpinum, (Lazio, Italy), 3 January 106 BCE**
Died **Rome, (Italy), December 43 BCE**

Cicero produced a critique of astrology and discussed the relationship of the stars and the soul.

Marcus Cicero, the Roman orator, lawyer, and politician, was the elder of two sons of a wealthy aristocrat. Cicero married Terentia in 77 BCE and had one son, the soldier Marcus Tullius Cicero, born in 65 BCE.

Cicero studied law as a teenager, as well as philosophy under Philo, the former head of the Platonic Academy at Athens. At the age of 17 he joined the army under the command of Pompeius Strabo, the father of the future Pompey the Great. Cicero was deeply involved in Roman politics for the rest of his life, as a supporter of Pompey until the latter's death in 48 BCE. He was elected quaestor in 76 BCE at the minimum age of 30, thus qualifying for membership of the Senate, and became consul in 63 BCE at the minimum age of 42. Julius Caesar considered inviting him to join his government along with Pompey and Crassus in 59 BCE, and his refusal led to a brief decline in his political fortunes and exile to Macedonia in 58 BCE. Pompey engineered his recall to Rome in 57 BCE, and Cicero became a defender of constitutional values against dictatorship and was, for a time, effective head of the government in Rome. He welcomed Caesar's assassination in 44 BCE and became a leader of the opposition to Mark Anthony. Although he expected protection from Octavian (the future emperor Augustus), when Octavian made peace with Anthony in 43 BCE Cicero was caught attempting to escape and executed. A large number of Cicero's writings survive, including 58 speeches made to the Roman people or Senate, a cache of 800 letters discovered by the poet Petrarch in 1345, 7 philosophical texts, 6 rhetorical works (together with fragments of other writings), poems, and translations of Greek texts.

Cicero's importance in the history of astronomy lies in two main works, *De divinatione*, an examination of contemporary divination, including astrology, and the *Somnium Scipionis* (Dream of Scipio), a passage from the larger *De Republica* that deals with the soul's ascent through the stars. Both should be read within the larger context provided by *De natura deorum*, a discussion of the nature and existence of the gods, and *De fato*, a discussion of fate, which survives only in fragments. He also translated **Aratus**' *Phaenomena* and wrote a poem, *Aratea*, based on it.

De Republica, written in 54 BCE, is a dialog on the ideal state. The critical astronomical passage occurs in Book VI, in which general Scipio Aemilianus has a dream in which he is escorted through the stars by his grandfather, Scipio Africanus the Elder. The passage is designed to encourage the younger Scipio (and by inference all Romans) in the pursuit of patriotism and a virtuous and humble life. Of modern astronomical interest is Cicero's opinion that the Earth is very small, and there are stars that are much larger than we imagine and too far away to be seen. Most important though is Cicero's exposition (through Scipio's words) of a spiritual universe, modeled on **Plato**, in which the human soul is made of fire and hence derived from the stars. As all substances must return to their natural place, the soul must therefore return to the stars. Politicians, he believed, may accomplish this goal by ruling justly in line with God's will, while philosophers and musicians can do it by imitating the music of the spheres, the sounds the planets make as they rush through the sky.

The passage was preserved by **Macrobius**, who wrote a commentary on it around 400, and its discussion on the relation between the soul and the stars thus survived into the Middle Ages. This reinforced the idea, current in the European Middle Ages, that astronomy had significant spiritual implications and political applications, which in turn provided a justification for the practice of astrology.

De natura deorum was finished in 45 BCE, and Cicero started work immediately on *De divinatione*, which is closely related. His task was to discuss, first, the problem of whether, if the gods existed, they sent signs to humanity *via* natural and supernatural events, including the stars; and, second, the use, universal in the Mediterranean world and Near East at the time, of divination, including astrology, to advise on political strategy. The book is structured as a dialog between Cicero and his brother Quintus. Drawing on debates that had been current in Greek thought for the previous 300 years, Quintus put the case in favor of divination while Cicero, following the skepticism of the New Academy, held that certain knowledge was impossible and that the best that could be hoped for was an assessment of probabilities. Given that major political decisions as well as theological debates might hinge on whether the gods spoke through the stars or not, the discussion has a clear and immediate political purpose.

Quintus argued essentially that, if the gods exist, they must speak through the stars, an extension of Babylonian astral theology into classical thought. As an example he cited a lunar eclipse in Leo that preceded, and hence was a sign of, Alexander the Great's defeat of the Persians in 332 BCE. From the Stoic **Posidonius** he took the typically Greek argument that all things happen according to Fate, itself defined as "an orderly succession of causes wherein cause is linked to causes and each cause, of itself, produces an effect." Thus, to know the cause is to know the effect. To know how the stars move is to predict their future positions and, hence, if one accepts the connections between stars and the state, the consequences for politics as well as for individuals.

Cicero replied to Quintus with a critique of astrology, which was to form the basis of all subsequent skeptical criticism of astrology down to the present day and which includes the first philosophical separation of astronomy from astrology in the ancient world. Astronomical positions, he argued, could be foreseen because they were based on the laws of nature, but no such law could allow astrologers to predict who, for example, might inherit an estate. Cicero cited incorrect predictions made by astrologers for Roman generals, including Julius Caesar, argued that the planets are too distant to exert a measurable effect, and asked about the role of heredity and why people born at the same time have different lives. He pointed out that people born with physical defects might be healed by medicine, thus overruling the stars, and that the thousands of soldiers who died when Hannibal annihilated the Roman army at Cannae in 216 BCE must have been born with different horoscopes, although all died at the same time. Cicero asked whether all people who had the same profession were born under the same stars and why astrologers did not take cultural or climatic influences into account. He even challenged the notion of a connection between the Moon and the tides on the grounds that the two are completely unrelated.

Cicero was clearly critical of astrology, yet sympathetic to the Platonic and Aristotelian idea that humanity and the stars inhabit a single interdependent cosmos in which the stars are "divine intelligences" and are the origin of the fire of which the human soul is made. While the claims of the astrologers are inherently unlikely and their precise predictions destined to fail, stars, planets, and people are nevertheless intimately connected. Cicero thus set out the ground for the many debates on the spiritual nature and practical purpose of both astrology and astronomy in the Middle Ages and Renaissance.

Nicholas Campion

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Clairaut, Alexis-Claude

Born **Paris, France, 7 May 1713**
Died **Paris, France, 17 May 1765**

Alexis Clairaut was an outstanding mathematician and a prominent French Newtonian. Clairaut was the only one of twenty children of his parents to reach adulthood. His father, Jean-Baptiste Clairaut, taught mathematics in Paris and educated his son at home to an extremely high standard. Alexis used Euclid's *Elements* while learning to read, and by the age of nine had mastered N. Guisnée's classical mathematics textbook on algebra, differential calculus, and analytical geometry.

In 1726, at the age of 13, Clairaut read his first paper "Quatre problèmes sur de nouvelles courbes" to the Paris Academy of Sciences. After completing a work on double curvature curves, he was proposed for membership in the academy on 4 September 1729, but he was so young that his election was not confirmed by the king until 1731. Then, at the age of 18, Clairaut became the youngest person ever elected to the academy. He joined a small group of remarkable people who supported the natural philosophy of **Isaac Newton**: **Pierre de Maupertuis**, Voltaire, and the Marquise du Châtelet, who translated Newton's *Principia* into French in 1756 with many additions of Clairaut's own theories.

Clairaut was responsible for major advances in mathematics. After having studied with **Johann Bernoulli** in Basel, he published works on the calculus of variations and on the geodesics of quadrics. In 1734 he studied the family of ordinary differential equations that are named after him. In his textbook *Éléments d'algèbre*, published in 1749, Clairaut showed with great success why the introduction of algebraic notation was necessary. His book was used for teaching in French schools for many years and went through six editions. *Éléments de géométrie* was published in the year of his death.

Clairaut's first work in astronomy was his participation in the expedition to Lapland (1736–1737) led by Maupertuis, to measure a degree of longitude. The expedition was organized by the academy in order to solve the controversy between **Giovanni Cassini** and Newton about the shape of the Earth. In 1743 Clairaut published *Théorie de la figure de la Terre*, confirming the Newton calculation that the Earth is an oblate spheroid, *i. e.*, flattened at the poles. The book was a theoretical support to the experimental data from the Lapland expedition and also laid the foundations for hydrostatics.

Clairaut then turned to the three-body problem, in particular on the problem of the Moon's orbit. His first conclusions were that Newton's theory of gravity was incorrect. With Euler's support, Clairaut announced to the academy on 15 November 1747 that the inverse square law did not hold. However, a few months later, he realized that the difference between the observed motion of the Moon and the one predicted by the Newtonian theory was due to errors coming from the approximations that were being made in dealing with the three-body problem, rather than from the inverse square law of gravitational attraction itself. Thus, Clairaut announced to the academy on 17 May 1749 that his theory was now in agreement with the inverse square law.

In 1752 Clairaut published *Théorie de la lune*, where he made use of potential theory. This work was completed 2 years later with the publication of his lunar tables. He next applied his knowledge of the three-body problem to compute the orbit of Halley's comet (IP/Halley) and predicted the exact date of its return. This required much more accurate approximations than had the problem of the Moon. Calculations taking account of gravitational perturbations by Jupiter and Saturn were indeed monumental, requiring 6 full months of hard work for three gifted people. Clairaut asked the help of **Nicole Lepaute**, a female mathematician working at the Paris Observatory, and the young astronomer **Joseph de Lalande**. On 14 November 1758, he could announce their result to the academy – that the perihelion would occur on 15 April 1759. The actual date of perihelion turned out to be 13 March. When the comet appeared, only 1 month before the predicted date, Clairaut was given great public acclaim.

Clairaut also made important contributions to the problem of aberration of light. He suggested an improved telescopic design using lenses made up of two different types of glass. Clairaut wrote several memoirs on the topic, but died at the age of 52 after a brief illness, leaving the work unfinished. By that time he had been honored by being elected to the Royal Society of London and the academies of Berlin, Saint Petersburg, Bologna, and Uppsala.

Jean-Pierre Luminet

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Clark Family

Clark, Alvan

Born **Ashfield, Massachusetts, USA, 8 March 1804**
Died **Cambridgeport, Massachusetts, USA, 19 August 1887**

Clark, Alvan Graham

Born **Fall River, Massachusetts, USA, 10 July 1832**
Died **Cambridgeport, Massachusetts, USA, 9 June 1897**

Clark, George Bassett

Born **Lowell, Massachusetts, USA, 14 February 1827**
Died **Cambridgeport, Massachusetts, USA, 20 December 1891**

In the history of astronomy, there has rarely been a family of telescope makers quite like that of Alvan Clark and his sons Alvan Graham Clark and George Bassett Clark. In the later half of the 19th century, few manufacturers, either in America or abroad, could match the quality reputation of the firm of Alvan Clark & Sons. The Clark firm produced nearly 600 telescopes in a 50-year span while never employing more than a handful of workers. From the time they began work in the early 1860s on their first large refractor, an 18.5-in. telescope intended for the University of Mississippi, to their final masterpiece in 1897, the 40-in. refractor for the Yerkes Observatory, the Clarks were on the leading edge of technology for large optical systems.

Alvan Clark began his career as an artist, first as an engraver, later as a portrait painter specializing in miniatures. He achieved considerable success in this regard. The Clark family became interested in telescope making in 1844 when George melted down the cracked dinner bell of his school, the Phillips Academy of Andover, Massachusetts, to convert it to a speculum metal mirror for a school project telescope. Alvan joined in his son's work and, as is often the case in father–son projects, seems to have virtually taken over. After producing several metal mirrors, Alvan switched to making lenses and made his first telescope sale in 1848.

Clark's sons, Alvan Graham and George Bassett, were essentially trained as craftsmen and mechanics; neither gained a college education. Both sons were trained in mechanical arts, but eventually George specialized as the machinist and instrument maker while Alvan Graham followed his father as an optician. Alvan Clark was not a mathematical optician, and the firm did not employ one for many years.

Unaccountably, perhaps due to his lack of a scientific education, Clark's reputation as an optician grew slowly at first, even though several astronomers in the United States pronounced Clark's lenses as excellent. However, his reputation received a boost through his sales of lenses in England. The "eagle-eyed" British double-star observer **William R. Dawes** bought several Clark lenses, widely extolled their virtues, and sold several to colleagues.

The reputation of Alvan Clark & Sons was strongly enhanced in 1860 when the firm was asked to undertake the manufacture of an 18.5-in. refractor lens for the University of Mississippi. At the time it was the world's largest lens. After moving into a new, larger facility and acquiring the lens blanks from the Chance Brothers of England, work was finally begun on the large lens. Much of the polishing was done by hand rather than by machine, and all of the final figuring of the lenses was done by hand. While testing this lens on 31 January 1862, Alvan Graham discovered the white dwarf companion of Sirius, the first everseen. The existence of this faint star had been predicted 20 years earlier by **Friedrich Bessel**, but though many had searched for it the companion had never been observed. By the time the lens was completed, however, the Civil War had erupted and the University of Mississippi was no longer able to pay for it. The 18.5-in. telescope including the lens was eventually installed in the Dearborn Observatory of the old University of Chicago.

Alvan Clark & Sons were the manufacturers of a number of other telescopes, which, at the time of their manufacture, were the "world's largest" of their type. These included the 26-in. United States Naval Observatory refractor (1873), the 30-in. Pulkovo Observatory refractor (1885), and the Lick Observatory 36-in. refractor (1888) in addition to the Yerkes 40-in. refractor (1897) previously mentioned. They were also responsible for a number of other large refractors of reputed high quality, including those at Chamberlin Observatory (20 in.), Lowell Observatory (24 in.), and Van Vleck Observatory (20 in.).

Alvan Clark's legendary proficiency in figuring near perfect lenses has been the source of a number of stories, most certainly apocryphal, including an allegation of his ability to feel submicroscopic imperfections in the glass surface by touch alone. However, since the Clarks still worked in an age where craftsmen's manufacturing techniques tended to be kept secret and many of the Clark's papers have been lost, there is no record of their exact polishing and testing procedures. It is known with certainty that Alvan Clark was a proponent of the method of local correction. Because of the impurities and structural defects in the optical glass then available, such correction in small zones was almost a necessity in producing good lenses.

In addition to their telescope-making work, the Clarks also contributed to observational astronomy. Both Alvan and Alvan Graham observed many double stars, most often as test objects to judge the performance of their lenses. Alvan, in particular, discovered a number of multiple stars that had been missed by **Friedrich Struve**, **Otto Wilhelm Struve**, and others. Dawes was astonished at Alvan Clark's visual acuity as well as the quality of his lenses. The Clarks were also among the early experimenters in astronomical photometry, making quite accurate measurements of the brightness of the Sun and Moon using an optical photometer of their own design. The younger Clarks participated in several solar eclipse expeditions. George and Alvan Graham journeyed to Shelbyville, Kentucky, to observe the total eclipse of 7 August 1869. George Clark was able to obtain a number of excellent photographs of the eclipse on that occasion. Alvan Graham joined two later eclipse expeditions at the

22 December 1870 and 29 July 1878 total solar eclipses, photographing the latter.

Alvan Clark received many awards, including honorary masters' degrees from Amherst College (1854), Princeton University (1865), the old University of Chicago (1866), and Harvard University (1874). The American Academy of Arts and Sciences awarded him its Rumford Medal. Alvan Clark was a member of the American Association for the Advancement of Science. Alvan Graham Clark won the Lalande Prize of the French Academy of Sciences for his discovery of Sirius's companion.

Gary L. Cameron

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Claudius Ptolemaius

➜ **Ptolemy**

Clausen, Thomas

Born **Snogbaek, Denmark, 16 January 1801**
Died **Dorpat (Tartu, Estonia), 23 May 1885**

Thomas Clausen was a specialist in the field of celestial mechanics and directed the Tartu Observatory (1865–1872). He was born into a poor family. At the age of 12, Clausen was sent to look after the cattle of a local priest. Father G. Holst discovered outstanding intellectual abilities in the boy and taught him Latin, Greek, mathematics, and astronomy. His later education was self-acquired. In 1823, Holst introduced Clausen to **Heinrich Schumacher**, director of the Altona Observatory and the founding editor of the *Astronomische Nachrichten*. Clausen handed to Schumacher a manuscript describing a method of measuring geographic longitudes by timing occultations of stars by the Moon. Clausen's work was of high quality, and he became an assistant at Altona Observatory in 1824.

Four years later, Clausen succeeded **Joseph von Fraunhofer** at the Optical Institute at Munich. His position, however, carried few specific duties, and he was left alone to undertake research in astronomy and mathematics. In 1842, he was invited by **Johann von Mädler** to become the astronomer at Tartu Observatory. There, Clausen's post was officially named astronomer–observer, but in reality he conducted only limited observations. These were determinations of stellar positions (adopted from a star catalog of **James Bradley**) that were later used by Mädler to calculate the proper motions of stars. For most of the time, Clausen was engaged in theoretical research. Upon Mädler's retirement in 1865, Clausen succeeded him as director of the observatory and professor of astronomy. Clausen himself retired in 1872 and afterward lived quietly in Tartu.

Clausen published numerous papers on celestial mechanics and practical astronomy, as well as on pure and applied mathematics. He calculated the orbital elements of 14 comets and presented the concept of cometary families. His work on the orbit of the comet D/1770 (Lexell) – one of the closest approaches on record of a comet to the Earth – won him a prize from the Copenhagen Academy. About Clausen's work, **Friedrich Bessel** wrote, "What a magnificent, or rather, masterful work! It is an achievement of our time which our descendants will not fail to credit him with." In mathematics, Clausen presented a new definition of the lemniscate and proved several new theorems. He was the first (in 1849) to solve the so called Lagrange problem. Clausen calculated the number π to 250 digits.

Despite his lack of formal education, Clausen was awarded a honorary doctorate from Königsberg University (1844), made a honorary member of the Royal Astronomical Society (1848), and a corresponding member of the Göttingen Scientific Society (1856). That same year, he became a corresponding member of the Saint Petersburg Academy of Sciences. Clausen was offered, but refused, the title of full academician, because it would have been necessary for him to relocate to Saint Petersburg.

Mihkel Joeveer

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Clavius, Christoph

Born **Bamberg, (Bavaria, Germany), 25 March 1538**
Died **Rome, (Italy), 6 February 1612**

Christoph Clavius was one of the most respected and widely published authors in the fields of mathematics and astronomy during the late 16th and early 17th centuries. His books were widely used, especially in the pervasive network of Jesuit colleges, and through them he was recognized as an authoritative interpreter and commentator on such fundamental ancient authors as **Ptolemy** and Euclid, as well as on contemporary authors and issues, including the early debates over Copernican cosmology. Clavius also served as one of the two astronomers on Pope Gregory XIII's commission to reform the Western calendar. As such he was the primary architect of the technical aspects of the reform, which was promulgated in 1582. Clavius subsequently became the most prolific defender of that reform against its critics.

Little is known of Clavius's early life aside from his birth date and place. In 1555, he entered the Society of Jesus at Rome and was dispatched to be educated at the Jesuit College of the University of Coimbra, in Portugal. He remained there long enough to observe the total solar eclipse of August 1560, which he later wrote about. By mid-1561 Clavius had returned to Rome to pursue theological studies in the Jesuit Collegio Romano; he began teaching mathematics there by 1563 and was ordained in 1564. By 1570, he had published the first edition of his *Commentary on the "Sphere" of Sacrobosco*, and in 1574 appeared his edition of Euclid's *Elements*, both of which he revised and republished multiple times. Clavius observed the Nova of 1572 and published (in his *Sphere* commentary) observations showing that it must have been located among the fixed stars, which led him to announce that the heavens could not be completely unchanging.

In the mid-1570s Clavius began serving on the pope's calendar reform commission, where he helped review the details and explain the technical merits and deficiencies of the various possible reform schemes. In the end it was his recommendation that determined the reformed calendar adopted by the commission.

In the course of his career, Clavius published textbooks for nearly every subject in the mathematical curriculum (into which category astronomy and astronomical instruments fell), including works on arithmetic, algebra, spherical and plane geometry, and gnomonics, as well as practical books on the sundial and astrolabe. In addition to his prolific publications, Clavius trained several generations of influential scholars and thus made astronomy a field in which the Jesuits of the 17th century could justly claim expertise.

Clavius's identity as the great defender of Ptolemaic cosmology derives entirely from his textbook on basic astronomy, the *Commentary on the "Sphere" of John of Holywood*, which underwent seven revisions and over 16 printings between 1570 and 1618. In addition to presenting a complete treatment of the spherical and observational astronomy of his day, Clavius introduced the basics of planetary theory and expounded and defended vigorously the Ptolemaic/Aristotelian cosmos. He also critically reviewed several alternatives to Ptolemaic theory, including homocentric, Copernican, and some other contenders today less well known – though not the Tychonic. Clavius's popular textbook makes clear that the diversity and vitality of competing cosmological theories went well beyond the Ptolemaic–Copernican debate even before **Galileo Galilei's** entry into the arena. Thus Clavius's criticisms of the Copernican theory set the astronomical terms of the debates into which Galilei would soon wade. Clavius's response to **Nicolaus Copernicus**, which appeared virtually unchanged in all editions of his *Sphere* commentary from 1581 on, rested on astronomical, physical, scriptural, and methodological arguments. The first three categories of arguments are part of his general case for the centrality and stability of the Earth and do not explicitly name Copernicus, although they are clearly intended to apply to him. The astronomical and physical arguments are, generally speaking, repetitions of the traditional arguments intending to show that astronomical appearances would be different from what we observe were the Earth not central and stationary, giving observational arguments showing that the Earth must be motionless, and citing physical arguments that a moving Earth is an impossibility. Clavius also quoted scriptural passages attesting to the centrality and immobility of the Earth. He specifically stated that Copernican cosmology contradicted Scripture, but he did not state or imply that theories inconsistent with scriptural evidence were heretical or dangerous. They were simply wrong. When he did confront Copernicus's theory directly, Clavius admitted that it was, unlike all of the other cosmological alternatives, as astronomically viable and technically useful as the Ptolemaic. But his critique then took a novel methodological tack in which he argued that the Copernican approach is logically equivalent to a false syllogism, in which false premises (*e. g.*, the motion of the Earth) can lead to true conclusions. False syllogisms, Clavius observed, work only because the correct outcome is known ahead of time, and such reasoning is incapable of producing certainty in conclusions based on it.

Clavius and Galilei were acquainted with one another and had corresponded occasionally from at least 1587. Indeed, in his own university lectures, Galilei drew heavily on Clavius's work. Clavius's "academy" of mathematicians at the Collegio Romano took an ongoing interest in astronomical matters and made occasional observations; some of them had even been experimenting with primitive astronomical telescopes, and observing with them, as early as the summer of 1610. So Clavius and his colleagues were well prepared when Cardinal Bellarmine asked them, in April 1611, for their opinion on Galilei's telescopic discoveries. Their reply was a strong endorsement of the accuracy of his observations, though not of the Copernican interpretations that Galilei drew. Clavius showed nearly the same attitude in his announcement of Galilei's discoveries, in the final revision of his *Sphere* commentary, published in 1612. This ringing endorsement was one of the earliest and most authoritative published affirmations of the truth of Galilei's discoveries. Clavius, in his published statement, went cautiously beyond the report to Bellarmine and, although declining to pursue their full implications, admitted that the impact of the new discoveries obliged astronomers to reconsider accepted planetary theories.

James M. Lattis

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Clemence, Gerald Maurice

Born **Greenville, Rhode Island, USA, 16 August 1908**
Died **Providence, Rhode Island, USA, 22 November 1974**

United States Naval Observatory astronomer (and later Yale University professor) Gerald Clemence calculated a definitive orbit for Mars, following in the footsteps of **Simon Newcomb**. With **Dirk Brouwer**, Clemence wrote a classic textbook on stellar kinematics. He was also president of the International Astronomical Union commission on ephemerides.

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Cleomedes

Flourished ***circa 200***

Cleomedes was a Stoic philosopher who was active around 200. This date is inferred from the internal evidence of his sole surviving treatise, *Caelestia* (The heavens). This treatise includes polemical attacks against Peripatetics (followers of **Aristotle**) and Epicureans that are characteristic of debates between Stoics and other philosophers during the 1st and 2nd centuries and that cease by the early 3rd century. Attempts to date Cleomedes to the 4th century on the basis of an astronomical observation reported at *Cael.* 1.8.46–56 are not warranted by the text.

The *Caelestia* is actually an astronomical digression in a series of lectures on Stoic philosophy offered by Cleomedes. Thus, it tells us much more about Stoicism at the time, and the desire to follow **Posidonius** in defining astronomy as a science that takes its starting points or first principles from physical theory and cosmology, than it does about current astronomical theory. Indeed, the astronomy it presents is elementary and limited to the following topics: the celestial sphere, the division of the world into zones, seasonal and climatic differences (1.1–4), the sphericity and centrality of the Earth (1.5–6), the absence of parallax in observations of the Sun and beyond (1.8), the sizes of the heavenly bodies (2.1–3) (specifically, **Epicurus**' claim that they are the size they appear to be), the illumination and phases of the Moon (2.4–5), and lunar eclipses (2.6). There is a brief appendix (2.7) giving values for planetary latitudes and elongations.

For historians of astronomy, the *Caelestia* is important mainly for offering two geometrical arguments estimating the size of the Earth, one attributed to **Eratosthenes** and the other to Posidonius (1.7). The presentation of these arguments, however, is plainly governed by Cleomedes' determination to show in accordance with Stoic epistemology how the heavens may still be the object of knowledge, though they are not in general the subject of cognitive presentation (sense perception that is veridical and self-certifying). It is, therefore, difficult to assess the historicity of these accounts, and in particular that attributed to Eratosthenes, given that the value for the circumference of the Earth ascribed by Cleomedes to Eratosthenes differs from that reported in numerous earlier sources.

Alan C. Bowen

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Cleostratus of Tenedos

Flourished **(Turkey), circa 500 BCE**

Cleostratus is credited, along with **Eudoxus**, with trying an 8-year cycle to commensurate the lunar and solar calendars. However, the claim that he invented the Greek zodiac is most probably legendary. A crater on the Moon is named Cleostratus.

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Clerke, Agnes Mary

Born **Skibbereen, Co. Cork, Ireland, 10 February 1842**
Died **London, England, 20 January 1907**

As a historian and commentator on science, Agnes Clerke communicated with such clarity and understanding that she raised substantive questions of value to ongoing research in astronomy and astrophysics. Clerke was the second child and younger daughter of John William Clerke, a bank manager who later became a court registrar, and his wife Catherine Mary (*née* Deasy). The father, a graduate of Trinity College, Dublin, was a scholarly man who continued through life to pursue his interest in the sciences, while her mother was an intellectual woman with a talent for music.

Agnes and her sister Ellen were educated entirely at home by their parents who brought them to an academic level unusual for women of that generation. Astronomy and music were Agnes' favorite subjects. Under her father's tutelage she worked her way through a substantial library of astronomical books. Later, her brother Aubrey, who excelled in mathematics and physics at university, introduced her to more advanced topics.

When Agnes was 19, the family moved to Dublin. After 6 years' residence there, the Clerke sisters spent 10 years in Italy, principally in Florence, where they continued their studies and became fluent linguists. In 1877, the family was reunited and settled permanently in London.

In that year Clerke, at the age of 35, commenced her career as a professional writer when she published the first of her anonymous articles in the erudite *Edinburgh Review*. Her name soon became known through her signed scientific biographies of **Galileo Galilei**, **Pierre de Laplace**, and other noteworthies in the *Encyclopedia Britannica*, begun in 1879. She also began to write regularly on astronomy for *Nature*, *The Observatory,* and *Knowledge*.

Through her London literary connections Clerke made the acquaintance of **Joseph Norman Lockyer** and, by correspondence, of **Edward Holden**, director of Lick Observatory in California. With encouragement from both Lockyer and Holden, she tackled a history of the "New Astronomy" (or astrophysics), which resulted in the work for which she is best known: *A Popular History of Astronomy during the Nineteenth Century*, published in 1885. The *History* was an immediate success for its usefulness to the professional astronomer and its appeal to the general reader. It brought her a wide circle of astronomer friends on whose behalf she could be an influential propagandist, such as **William** and **Margaret Huggins** and **David Gill**. The *History* was revised three times, in four editions, in its author's lifetime. Its continued popularity to the present day rests in its thoroughness, and the reliability of its dates, data, and details.

In 1888, Clerke spent 3 months at the Royal Observatory, Cape of Good Hope, as the guest of its director **David Gill**. There she had the opportunity – the only one in her entire career – of taking part in actual astronomical observations. The outcome was her second major book, *The System of the Stars* (1890), which strongly advocated a Universe consisting of only one galaxy—our Milky Way, the most favored model at that time. It was not until several decades after Clerke's death that the spectroscopic explorations of **Vesto Slipher** and the photographic surveys initiated by **Edwin Hubble** convincingly resolved the debate over the nature of the galaxies.

Clerke's third major book, *Problems in Astrophysics* (1903), attempted to identify unresolved questions, especially in stellar spectroscopy, and to suggest projects that might solve them. Many of her contemporaries deemed this book her most impressive. Nevertheless, Clerke did have her critics, notably in the journal *Nature*, which found fault with her as a bystander with no direct experience of observational or laboratory procedures.

Clerke's 150 biographical entries in the original volumes of the *Dictionary of National Biography* constitute a valuable contribution to learning. She also took a keen interest in the "new physics" of radioactivity and allied phenomena at the end of the 19th century. Some of her brilliant essays on these and other topics, published in the *Edinburgh Review*, being unsigned have not been universally recognized as hers.

Clerke died after a brief illness at her London home. She is buried in the family plot in Brompton Cemetery, London.

Mary T. Brück

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Coblentz, William Weber

Born **North Lima, Ohio, USA, 20 November 1873**
Died **Washington, USA, 15 September 1962**

American physicist William Coblentz made major contributions to radiometry, the quantitative measurement of the amount of radiation emitted by sources, or hitting surfaces, and established the foundations of infrared spectroscopy. He received degrees from the Case School of Applied Science in Ohio (BS: 1900; Sc.D.: 1930) and Cornell University (Ph.D. in physics: 1903). From 1905 to 1945, Coblentz was chief of the Radiometry Section of the United States National Bureau of Standards and was instrumental in devising standardized methods of measuring the brightness and energy content of radiation, in the visible, infrared, and ultraviolet bands. He was particularly interested in the infrared spectrum of iodine. From 1903, Coblentz investigated the spectra of hundreds of substances, organic and inorganic; his work with rock salt was thorough and accurate, so much so that many of his spectra are still usable. He was the first to determine accurately the constants of blackbody radiation, thus verifying Planck's Law.

Astronomy was not Coblentz's major interest, but his precision measurements of the amount of radiation received from stars in 1914 and 1921 played a role in accurate calibration of the magnitude scale, and later, in collaboration with **Seth Nicholson** and **Edison Pettit**, he made the first systematic, quantitative measurements of infrared fluxes from stars. Most significant was his application of thermocouple detectors to the determination of the infrared radiation coming from Venus, Mars, Jupiter, and Saturn, in collaboration with **Carl Lampland** and **Donald Menzel**. They were able to separate the radiation we receive from the planets into a reflected and a reradiated component and to show that the sum was very nearly equal to the total energy the planets receive from the Sun. Later, more accurate measurements have shown that somewhat more energy comes from Jupiter and Saturn than they are receiving (*i. e.*, their interiors are still contracting very slowly), but the Coblentz *et al.* data proved that the difference must be small, and Jupiter was not in any way a star.

Coblentz received medals from the Paris Academy of Sciences, the American Academy of Arts and Sciences, the Optical Society of America, and the International Union of Photobiology. In addition to being a member of all the societies of obvious importance to his research, he was a member of the Society for Physical Research and the American Medical Association, and he listed among his research interests the physical study of fireflies, bioluminescence, and phototherapy.

Richard Baum

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Cole, Humphrey

Born **possibly Yorkshire, England, *circa* 1520–1530**
Died **London, England, 1591**

Humphrey Cole was a highly skilled scientific instrument maker.

While the date of Humphrey Cole's birth is unknown, his writings suggest it was around 1520–1530. He was raised in the north of England, most likely Yorkshire. Cole's wife Elizabeth survived him, and it is not known if he had any children.

Cole's early employment for the Crown in the Tower mint from around 1558 to about 1578 shaped his later life work. As a diesinker or sinker of irons, his job was to produce the dies used to strike coins. Feeling that the salary was "lacking sufficient maintenance for me and my family," Cole looked for additional sources of income. His metallurgical knowledge helped him become part of the group that established the Company of Mineral and Battery Works, which received its Royal Charter in 1568. In addition, the Crown appointed him in 1577 and 1578 to be one of the cómmissioners who examined the ore brought by Martin Frobisher from North America to England.

Richard Jugge, a printer and publisher of Bibles, commissioned Cole to engrave a map of the Holy Land for the 1572 edition of the *Bishops Bible*. This is Cole's only known map and one of the earliest maps engraved by an Englishman.

Thomas Digges in 1576 republished his father's (**Leonard Digges**) *A Prognostication of Right Good Effect* to which he added *A Perfit Description of the Cælestiall Orbes.* Cole received a commission from Digges to produce an engraving with the same title, *A Perfit Description of the Cælestiall Orbes*. This engraving and publication were the first English illustration and discussion of the Copernican world system. Around the Sun are the orbits of Mercury, Venus, Earth, Mars, Jupiter, and Saturn. The Moon is depicted going around the Earth. Surrounding the orbit of Saturn is "This Orbe of Starres fixed infinitely up extendeth hit self in altitude sphericallye."

The production of scientific instruments became another income source for Cole. Twenty-six of his instruments, dated from 1568 to 1590, are known to survive. Contemporary instrument makers used wood, but Cole used brass or silver. There is no evidence that Cole made any instruments out of cheaper wood. His masterpiece is a 2-ft.-diameter astrolabe, dated 1575, that currently is owned by the University of Saint Andrews, Scotland. The instrument was designed to have three plates for use at different latitudes. Two plates have been lost, but the one for 52° (central England) exists. Cole's theodolite dated 1586 is one of the oldest known.

Cole produced many pocket astronomical compendia. These complex devices contained several instruments and tables. Commonly included were sundials, compasses, nocturnals (used for telling time at night from the position of the stars), and perpetual calendars. Some included astrolabes, theodolites, and drawing instruments. A 3-in. × 2-in. oval astronomical compendium made in 1569 for Sir Francis Drake, prior to his first voyage to the West Indies, included an instrument that allowed Drake to determine the time of the tides.

Cole produced many navigational aides for Martin Frobisher's three voyages of exploration to Baffin Island between 1576 and 1578. The "Armilla Tolomei" was an armillary sphere with the constellations. The "Compassum Meridianum" was another instrument used to determine compass deviation. The "Holometrum Geometricum" was an early precursor to the theodolite. The "Horologium Universale" and "Annalus Astronomicus" were used to establish time by measuring the Sun's altitude at a fixed latitude. The "great globe of metal in blanke" probably was a terrestrial globe without land markings used to instruct prospective mariners to lay a course. The "Sphera Nautica" probably was a globe with rhumb lines or a device for finding the compass deviation from north.

Cole produced scientific instruments almost to the time of his death. The quality of his instruments is superb, and he should be considered as the founder of the English scientific instrument trade.

John W. Docktor

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Comas Solá, José

Born **Barcelona, Spain, 19 December 1868**
Died **Barcelona, Spain, 2 December 1937**

José Comas Solá was the leading astronomer in Spain at the beginning of the 20th century. Born and educated in Barcelona, Comas Solá made his first astronomical observations in 1886 at the private observatory of Rafael Patxot in Sant Feliu de Guixols. He studied at the College of Physical and Mathematical Sciences of the University of Barcelona, graduating in 1889. In that year he began observing Mars with a 6-in. Grubb refractor, continuing his observations through all subsequent oppositions of this planet. By 1894 Comas Solá had accumulated enough observations to produce an albedo map of Mars. Extending his observations to other planets, Comas Solá determined the rotational period of Saturn in 1902.

After being elected to the Barcelona Academy of Sciences and Arts in 1901, Comas Solá was founder and first director of the Fabra Observatory of the academy between 1903 and 1937. The observatory, located on the hill Tibidabo, was equipped in 1904 with a double refractor with 38-cm diameters and focal lengths of 6 m and 3.8 m, respectively. The dome was mounted on a building with octagonal ground plan, the meridian room and another tower with meteorological instruments were added to the west.

Many of Comas's works concerned the planets and comets. He discovered two comets: C/1925 F1 (Shain–Comas–Solá) on 23 March 1925 (the first comet discovered from Spain in 300 years) and 32P/1926 V1 (Comas Solá) on 5 November 1926. Comas also discovered 11 new asteroids.

Comas was the first president of the Sociedad Astrónomica de España y América and editor of its journal *Urania* (Barcelona). This society still exists and has about 760 members. Most of his books show his interest in popularizing astronomy.

He is honored by the naming of two of his asteroid discoveries (1655) Comas Solá and (1102) Pepita, the feminine form of Pepito, the familiar name of the discoverer. Also, a crater on Mars bears the name of this astronomer.

Christof A. Plicht

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Common, Andrew Ainslie

Born **Newcastle upon Tyne, England, 7 August 1841**
Died **Ealing, (London), England, 2 June 1903**

Andrew Common demonstrated the value of using large reflecting telescopes to photograph celestial objects. Through his improved techniques for guiding telescopes, which made possible comparatively long exposures, Common proved that photography could record substantially greater detail than could be seen with the naked eye.

Common's father, Thomas Common, a distinguished surgeon of the North country who was renowned for his treatment of cataract, died during Andrew's infancy, and economic misfortunes beset the family. During those years of hardship, when Common was about 10, his mother borrowed a telescope for him from Dr. Bates of Morpeth. Although Common showed great interest in the instrument, he had no real opportunity to exercise his astronomical inclinations for many years thereafter and, instead, struck out on his own at a very young age to seek training and employment.

Common was fortunate that an uncle was active in the firm of sanitary engineers, Matthew Hall & Company, of London. Young Common joined the firm at a low level, and over the years proved his worth in positions of increasing responsibility. He eventually became the general manager of the firm, which succeeded so well under his leadership that he was able to retire in 1890.

As his position at Mathew Hall & Company became more settled, in 1874 Common made his first attempts at celestial photography with a 5.5-in. equatorially mounted refractor from his home in London. Two years later he was elected a fellow of the Royal Astronomical Society, and about the same time he moved to Ealing where he lived for the remainder of his life. There Common planned to enlarge his range of equipment with a large reflecting telescope, and to this end obtained two 17-in. glass disks with the intention of grinding a mirror. However, he changed his mind and ordered an 18-in. silver on glass reflector from Calver, the mounting of which he designed himself. Observation commenced in 1877, and in the following January Common communicated observations of Deimos, the outer satellite of Mars, and of the satellites of Saturn, to the Royal Astronomical Society.

Aware of the great potential of celestial photography, Common devoted particular attention to the way in which telescopes are mounted, and published a "Note on Large Telescopes, with Suggestions for Mounting Reflectors" in the *Monthly Notices of the* Royal Astronomical Society, April, 1879. He applied those ideas in mounting a 36-in. mirror by Calver, the construction of which showed great engineering skill. The main moving part, the polar axis, floated on Mercury to reduce friction. To compensate for clock-drive errors, Common devised a photographic plate holder that could be moved during exposure. This allowed a lengthening of exposure time, and distinguished him as the first to succeed in taking long exposures.

With the 36-in. telescope, Common made visual observations of the satellites of Mars and Saturn, and the nebulosity in the Pleiades. On 24 June 1881, he photographed the great comet C/1881 K1, the same night it was photographed by **Henry Draper** in America. These were the earliest good photographs of a comet.

But although Common endeavored to register an image of the Orion nebula (M 42), it was not until 17 March 1882, following improvements to the clock drive and his advantageous use of increasingly sensitive photographic plates, that he obtained an image of such quality as to excite general admiration. Perfecting his guiding system still further resulted, on 30 January 1883 after an exposure of 37 min, in a superb picture of the nebula, which showed the superiority of a photograph over a drawing. A year later his efforts in celestial photography were recognized when he received the Gold Medal of the Royal Astronomical Society. Thereafter the 36-in. reflector was sold to Edward Crossley, of Halifax, England, who later donated it to the Lick Observatory where it was extensively modified and then used for photography by **James Keeler**.

After taking a year out of astronomy, Common commenced his greatest task, the construction of a 60-in. reflector, the polar axis of which, a wrought iron cylinder 8 ft. in diameter, floated in a tank of water. It was a major and wearying venture. The instrument was finally ready for use in February 1889, but evidence of internal strain in the mirror was highlighted by a slight ellipticity in the images of stars, occasioning it to be refigured and resilvered in the spring of that year. Images were thus improved; nevertheless a second disk was ordered. Although a few excellent photographs were taken with the 60 in. reflector, Common's involvement in designing gun sights and telescopes for the army and the navy prevented him from making any further use of the telescope before his sudden death in 1903. Harvard College Observatory later acquired the 60-in. telescope.

Common was very generous to his astronomical colleagues whenever a mirror was wanted, and invariably supplied what was required. He made large mirrors for the Solar Physics Observatory, Cambridge; the National Physical Laboratory, England; and the Royal Society. The 16-in. coelostats he designed and made for the eclipse expeditions of 1896 amply testify to his mechanical and optical skill. The Sheepshanks telescope at Cambridge, England, and the Durham Almucantar also benefited from his attention.

Common served as treasurer of the Royal Astronomical Society (1884–1895), and as its president (1895/1896). He was elected a fellow of the Royal Society in 1885, and served on its council from 1893 to 1895. From 1894 he represented the Royal Society on the board of visitors of the Royal Observatory, Greenwich. In 1891 Common received the honorary degree of LLD from the University of Saint Andrews.

Obliged to strike out along the road to fortune at an early age, and with no one to advise him and to direct his course of study, Common was able to focus on his work with freshness and freedom. In the truest sense of the expression, he was a self-made man. The absence of self-seeking in his character, and a disposition to work for the good of astronomy, earned him the esteem and high regard of his fellow astronomers. In 1867 he married Ann Mathews; at his death his widow, one son, and three daughters survived Common.

Richard Baum

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Compton, Arthur Holly

Born **Wooster, Ohio, USA, 10 August 1892**
Died **Berkeley, California, USA, 15 March 1962**

American physicist Arthur Compton received the 1927 Nobel Prize (shared with C. T. R. Wilson, 1869–1959) in Physics for discovering the effect that bears his name. In the Compton effect, X-rays are scattered by individual electrons, with some of the energy of the X-rays being transferred to the electrons. Some modern detectors for γ rays and X-rays from astronomical objects make use of Compton scattering.

Compton was the son of a Presbyterian minister and professor of philosophy, Elias, and Otelia Catherine (*née* Augspurger) Compton. His older brother, Karl Taylor Compton (1887–1954), then president of the Massachusetts Institute of Technology, turned Arthur's interests from engineering to physics. As a student at Wooster College (bachelor's degree: 1913), Arthur invented and built a device (which he later improved) for measuring the rotation rate of the Earth and the observer's latitude from inside a closed laboratory, unrelated either to astronomical observations or to the Foucault pendulum. It was a circular glass tube, filled with a low-viscosity fluid, mounted in a plane perpendicular to the axis around which the rotation was to be measured. A quick 180° flip of the tube around an axis in its plane left the fluid rotating in the wrong direction relative to the tube. Compton found an Earth rotation period of about 1.034 days and a latitude for Princeton University of about 40°.

Compton's 1916 Ph.D. in physics from Princeton was, however, for work on the intensity of X-ray reflection and the distribution of electrons in atoms, carried out under Nobel Prize winner O. W. Richardson and H. L. Cooke. On 28 June 1916, Compton married Betty Charity McCloskey. They had two children: Arthur Alan (who became an officer in the United States State Department) and John Joseph (who became head of the Philosophy Department at Vanderbilt University).

After having taught physics in the period 1916–1917 at the University of Minnesota, Compton spent 2 years at the Westinghouse Electric and Manufacturing Company, in Pennsylvania (where he devised a new sodium vapor lamp). In these 2 years, Compton kept his interest in X-ray scattering; in 1919, he went to Cambridge, England, to continue his studies at Cavendish Laboratory. When Compton returned to the United States a year later, he was designated Wayman Crow Professor and became head of the Physics Department at Washington University, in Saint Louis, Missouri.

The 1923 discovery of the Compton effect, which Compton explained as collisions between individual X-ray quanta and electrons, strongly supported **Albert Einstein**'s corpuscular theory of light. The amount of energy transferred from X-ray to electrons depends on the scattering angle, the way it would for colliding billiard balls. Inverse Compton scattering, in which an energetic electron gives up some energy to a photon, is one of the sources of X-rays and γ rays emitted by astronomical objects. When these X-rays and γ rays reach a satellite above the Earth's atmosphere, a Compton-effect telescope can be used to determine their energies, directions of arrival, and (in a technology not yet fully developed) their polarization.

The same year, 1923, Compton moved to a professorship in physics at the University of Chicago, where he stayed until 1954, returning to Washington University as chancellor and distinguished service professor of natural philosophy until his retirement in 1961. At University, Compton discovered total reflection of X-rays from single crystals, and, with junior colleagues, measured the polarization of scattered X-rays and obtained the first X-ray spectra diffracted from ruled gratings used at grazing incidence.

Compton's other main interest at Chicago University was the study of cosmic rays. He led a worldwide investigation of the intensity of these as a function of geomagnetic latitude, longitude, and altitude, which confirmed earlier results that the incident rays must, in fact, be charged particles, subject to the influence of the Earth's magnetic field. Compton also discovered a dependence of cosmic ray intensity on atmospheric temperature and barometric pressure (in fact, on density), which was later interpreted by **Patrick Blackett** as the result of the production of secondary mesons by cosmic ray collisions with air molecules.

During the war years, 1941–1945, Compton was the chief of the project for the production of plutonium (for fission bombs) at the deceptively named Metallurgical Laboratory of the Army Corps of Engineers' Manhattan District at the University of Chicago. Famously, the scientists worked in a laboratory excavated underneath the stadium bleachers.

In addition to his Nobel Prize, Compton received awards from the American Academy of Arts and Sciences, the Radiological Society of North America, the Royal Society of London, and the Franklin Institute. Between 1934 and 1942, he served terms as president of the American Physical Society, the American Association of Scientific Workers, and the American Association for the Advancement of Science, his brother Karl having previously presided over the first and third of these.

Nadia Robotti and *Matteo Leone*

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Comrie, Leslie John

Born **Pukekoke, New Zealand, 15 August 1883**
Died **London, England, 10 December 1950**

Leslie Comrie was an early leader in the modernization of computing techniques for astronomy, pioneering the use of machines to both speed production and improve the accuracy of astronomical tables. Comrie was the elder son of John Alexander and Lois Helen

Comrie. His paternal grandparents immigrated to New Zealand from Scotland in the 1850s.

Comrie majored in chemistry and graduated with a BA from University College, Auckland, in 1915. He earned an MA in chemistry in 1916. Comrie developed an interest in astronomy while at University College and joined the British Astronomical Association [BAA] while still a student. After teaching for a short time at Auckland Grammar School, Comrie joined the New Zealand Expeditionary Forces and was in active service in France where he lost a leg during World War I. In 1919, Comrie was awarded a New Zealand Expeditionary Force Scholarship, which allowed him to study astronomy at Cambridge University under **Arthur Eddington**. He was awarded a Ph.D. in 1923 for his thesis on the occultation of stars by planets.

Comrie's principal astronomical interest was positional astronomy. As a graduate student at Cambridge University, Comrie made a detailed study of methods of predicting the occultation of stars by planets. This work had a twofold significance. First, it led to a revival of interest in the observation of planetary occultations; and, second, it helped to stimulate Comrie's interest in scientific computation and mathematical table making, an interest on which the rest of his career was based. In 1920, the BAA established a Computing Section to predict phenomena involving Saturn's satellites but later expanded the section's work to the prediction of other phenomena. Comrie was appointed as the Computing Section's first director and undertook to coordinate a group of 24 volunteers computing the necessary data. Comrie produced a "Computing Memoir" in 1921 and in 1922 issued the first British Astronomical Association *Handbook*. Comrie resigned as director of the Computing Section in 1922 when his career took him to the United States, but he continued to maintain an interest in the work of the section. Importantly, this work gave him valuable experience in organizing computations and seeing the results through press.

Comrie spent nearly 3 years in the United States, teaching astronomy and numerical computation at Swarthmore College and Northwestern University. While teaching in the United States, Comrie began to publish widely on mathematical tables and computing. His main concern at this time was the outdated computing methods being used by astronomers. He encouraged astronomers to adopt calculating machines for their work.

In October 1925, Comrie returned to England to take up a post as an assistant at the British Nautical Almanac Office. Comrie's appointment to the Nautical Almanac Office gave him the opportunity to implement his ideas on astronomical computation on a large scale. When he joined the office, computing was done by hand using logarithm tables with very few exceptions. Retired ex-employees were performing much of the work in their own homes. There was no mechanism for training new staff for the future. While the system worked well at that time, it was clear that this situation could not be sustained. As soon as he arrived, Comrie began to introduce commercial calculating machines and younger staff into the office. The first machines to be introduced were Brunsvigas, a Monroe, and a Comptometer. He then installed carriage-controlled adding and listing accounting machines and applied them to interpolation and differencing, devising new computing methods as he did so. Comrie's most spectacular use of machine computation was his application of Hollerith punched card machines to the Fourier synthesis needed to produce tables of the position of the Moon. This work had kept two members of staff fully occupied all year round. However, with the punched card technique and machinery, Comrie was able to produce tables for the next 15 years in only 7 months.

In March 1926, Comrie was promoted to deputy superintendent and in August 1930 took over as superintendent. Comrie made two major contributions as superintendent of the Nautical Almanac Office. His first achievement was that he completely revolutionized the computing methods used to prepare the predications given in the *Nautical Almanac*. Comrie's second achievement at the office was a complete revision of the structure of the *Nautical Almanac*. Aside from the additional publication of the *Nautical Almanac, abridged for the use of seamen* introduced in 1914, the form of the *Nautical Almanac* had remained largely unchanged since 1834. Comrie completely revised the *Nautical Almanac* to take account of advances in navigation, astronomy, computing methods, and typography. He also produced tables using the standard equinox of 1950.0 based on a suggestion he had made in a paper in the *Monthly Notices of the Royal Astronomical Society* in 1926. The publication of *Planetary Co-ordinates Referred to the Equinox of 1950.0* in 1933 led to a simplification of the calculation of special perturbations.

In parallel to his work at the Nautical Almanac Office, Comrie was also building up an international reputation as a mathematical table maker. He was responsible for the start of the British Association Mathematical Tables Committee series of mathematical tables, and personally published several tables. His desire to help others with their computational problems, and the level of outside computing work he carried out, led to his dismissal from the Nautical Almanac Office in 1936. However, he continued as a table maker and, while he did not hold another astronomical appointment, did maintain a lifelong interest in positional astronomy. In August 1937, Comrie set up the Scientific Computing Service as a commercial scientific computing bureau – one of the first of its kind. Comrie's new company provided invaluable support to British military operations early in World War II.

Comrie was elected fellow of the Royal Society in March 1950 for his contribution to computing and mathematical table making. He was also a fellow of the Royal Astronomical Society (serving on Council 1929–1933). Comrie was a member of the British Astronomical Association, the American Astronomical Society, the Astronomical Society of the Pacific, Sigma Xi, the New Zealand Astronomical Society, and the Astronomischen Gesellschaft. From 1928 onward, he was an active member of the International Astronomical Union, serving as president of Commission 4 (Ephemerides) from 1932 to 1938. Comrie was also secretary of the British Association for the Advancement of Science Mathematical Tables Committee from 1929 to 1936. A crater on the farside of the Moon is named Comrie.

During his lifetime, Comrie was well-known for his computational abilities, his energy, and his kindness and generosity, but he was also a blunt and forthright man, fanatical about his work. Although he would gladly offer help and advice, he expected his advice to be taken up with alacrity. His high standards of work and his emphasis on precision and accuracy meant that he did not suffer fools gladly, and he said so. While he will be remembered for his singular contributions to astronomy in the form of vastly improved ephemerides and working tables, Comrie was also responsible for the widespread adoption of commercial calculating machines into many branches of scientific computation and many improvements in mathematical table making and table typography outside astronomy. Comrie married twice: first in 1920 to Noeline Dagger (whom he later divorced) and second in 1933 to Phyllis Betty Kitto. Comrie had two sons, John and Julian, one from each marriage.

Mary Croarken

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Comstock, George Cary

Born **Madison, Wisconsin, USA, 12 February 1855**
Died **Madison, Wisconsin, USA, 11 May 1934**

George Comstock was a professor of astronomy and director of the Washburn Observatory of the University of Wisconsin. Comstock was the son of Charles Henry Comstock and Mercy Bronson. He spent his youth in Madison and Kenosha, Wisconsin, and Sandusky, Ohio. In 1869, the family moved to Adrian, Michigan, where George completed his secondary education. He gained admission to the United States Naval Academy, but his mother convinced him that a military career was dangerous. He then enrolled at the University of Michigan, and the family moved to Ann Arbor so George could reside at home. There he studied astronomy under **James Watson**, the second director of the Detroit Observatory, who was himself trained by **Franz Brünnow**. Following the financial panic of 1873, Watson made arrangements through general Marr of the United States Army for Comstock to earn some money by working as a recorder for the United States Corps of Engineers on the survey of Lake Ontario, Lake Erie, and Lake Superior, and of the Mississippi River in his final year of studies. Comstock worked as a surveyor for 6 months during the summer and attended the university the other 6 months. Following graduation in 1877, he worked for an additional year on the Mississippi River survey, and then at the Detroit Observatory in association with Watson and assistant astronomer **John Schaeberle**, another of Watson's students.

When Watson was appointed in 1878 as the inaugural director of the Washburn Observatory at the University of Wisconsin, Comstock followed him shortly thereafter as Watson's assistant. Watson died unexpectedly in late 1880, and Comstock stayed on under the new director, **Edward Holden**, who was slated to be the first director of the Lick Observatory. Comstock spent the remainder of his scientific career at Madison, leaving only for a brief teaching assignment as chair of mathematics and astronomy at the Ohio State University (1885–1887), and for a summer at Lick Observatory in 1886. Comstock intended to stay in California, but when Holden arrived to be director of Lick Observatory in 1886, Comstock returned to replace him as director of the Washburn Observatory.

While at Madison, Comstock studied law at the university as a fallback career, realizing that the study of astronomy might not always be a reliable source of income. He received his JD degree in 1883 and was admitted to the Wisconsin bar, although he never practiced. He considered his legal study to be possibly the most valuable part of his education because he learned to apply his knack for precision to his speech and his mental processes.

Comstock's fieldwork with the Lake Survey gave him the expertise that led to his *Textbook of Field Astronomy* (1901) and *Textbook of Field Astronomy for Engineers* (1902). His work under Holden on precision in astronomy led to numerous articles in the *Publications of the Washburn Observatory*, including determinations of the latitude and longitude of Washburn Observatory, star catalogs, observations of double stars, observations of minor planets and comets, and experiments on stellar color. Comstock also authored a determination of the aberration constant and atmospheric refraction that was the best of its day. He devised various pieces of scientific apparatus, including a slat-screen device to enhance use of the meridian-circle telescope, and a double-image micrometer. His painstaking work on double stars led him to detect the proper motion of stars as faint as the 12th magnitude. This led Comstock to the bold conclusion that the Milky Way was an absorption effect. The theory was disproved, but was astute at the time.

By 1899, Comstock was so highly regarded in the astronomical community that he was offered the directorship of the Nautical Almanac, a position he declined, preferring to stay in Madison.

In 1897, Comstock was among the founders of the American Astronomical Society, which he served as its inaugural secretary for a decade, and was president from 1925 to 1928. As an instructor, Comstock was popular with his students, teaching with dedication and inspiring his students to follow his example of hard work, high standards, and determination. He was elected to membership in the National Academy of Sciences in 1899, and received honorary doctoral degrees from the University of Illinois and University of Michigan in 1907. In 1894, Comstock married Esther Cecille Everett of Madison and had one daughter, Mary. After retirement, the Comstocks traveled around the world, and then settled in Beloit, Wisconsin.

Patricia S. Whitesell

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Comte, Auguste [Isidore-Auguste-Marie-François-Xavier]

Born **Montpellier, France, 19 January 1798**
Died **Paris, France, 5 September 1857**

Best known for inventing the word "sociology" and his "religion of humanity," Auguste Comte figured significantly in moving Western civilization away from an assumption that the social order must be grounded on religious faith and toward the modern sensibility, which depends on a scientific understanding of the world. Astronomy provided the model for his ideal of a rationally ordered society.

Comte was the eldest child of Louis-August Comte and Félicité-Rosalie Boyer. He grew up in the shadow of the French Revolution; the ideals behind it fueled his vision of a society based not on power relationships but on reason – what he came to call "positive politics." In 1817, the 19-year-old Comte became secretary to Claude Henri, Comte de Saint-Simon, an influential social philosopher. That association ended unhappily in 1824, as Comte's developing views began to conflict more and more with Saint-Simon's. But Comte was indebted to Saint-Simon for many of his ideas – often to a degree greater than he was eager to admit.

After leaving Saint-Simon, Comte became a mathematics tutor and later an admissions examiner at the École Polytechnique. He tried to acquire a tenured professorship several times, but was never successful. In 1824, Comte married Caroline Massin; the union was dissolved in 1842.

The germ of Comte's philosophical ideas first appeared in one of the "Opuscules" he wrote in 1822, while working for Saint-Simon. This fundamental essay contains the two basic concepts of Comte's positivism in embryonic form – the "law of three stages" and his classification of the sciences. From 1830 through 1842, he was engaged in writing his six-volume major work, the *Cours de philosophie positive* (*Course in Positive Philosophy*).

Comte's three stages in the progressive development of human knowledge are:

(1) the *theological stage*, during which mankind explains what is beyond his understanding by attributing those things to supernatural beings;

(2) the *metaphysical stage*, during which society attributes such effects to abstract but poorly understood causes; and

(3) the final *positive stage*, during which humans acquire an understanding of the scientific laws that control the world, cease to speculate about the ultimate causes of natural events, and seek instead merely to make use of them.

For Comte, science and scientific facts constituted the only valid way of knowing the world; a religious way of knowing would be for him a self-deception.

The other component of Comte's positivism was his classification of the sciences in the "necessary and invariable" order by which they became positive: astronomy, physics, chemistry, biology, and sociology. Mathematics was not included by Comte because, as he argued, it lay above and beyond the rest as the basis for all the sciences. He did not consider psychology, which relied too much on introspective observations, to be a science. Much of Comte's major work, the *Cours de philosophie positive*, was given over to the demonstration that each science was dependent upon the development of the previous one. Citing the achievements of mathematical astronomers **Pierre de Laplace** and **Joseph Lagrange**, Comte argued that astronomy must inevitably mature before physics, physics before chemistry, and so forth.

Astronomy lay at the top of the hierarchy, in Comte's judgment, because it was concerned only with the positions and motions of celestial bodies (*i. e.*, to "save the phenomena"). In turn, astronomy's role as an observational, rather than experimental, science carried another important implication for Comte. He considered it an impossibility that astronomers would ever learn the composition of celestial bodies. Less than a generation later, however, his "prediction" was rudely overturned by the emergent science of astrophysics, led by the pioneering spectral analysis of chemists **Robert Bunsen** and **Gustav Kirchhoff**.

Comte looked upon the mathematical precision and certainty of astronomy as a model for a more rational society, and he furthered the idea that science, rather than religion, could become the foundation of the social order. The remainder of Comte's life was devoted to establishing a "positive religion" or "religion of humanity," complete with a calendar of "positive saints" and a catechism. Zoologist Thomas Henry Huxley once characterized Comte's "religion of humanity" as "Catholicism *minus* Christianity."

Despite its shortcomings, Comte's philosophy influenced many important thinkers throughout the 19th century, including John Stuart Mill, Harriet Martineau, Herbert Spencer, and George Henry Lewes. Although the 20th-century movement known as "logical positivism" was to some extent an outgrowth of Comte's philosophy, its concerns generally lay beyond Comte's purview. Indirectly, Comte's ideas furthered the rise of the scientific intelligentsia and its separation from the humanistic intellectual tradition, a dichotomy that was identified in C. P. Snow's famous 1959 essay, "The Two Cultures."

Glenn S. Everett

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Comte de Buffon

➜ **Leclerc, Georges-Louis**

Comte de Pontécoulant

➜ **Le Doulcet, Philippe Gustave**

Condamine, Charles-Marie de la

Born **Paris, France, 28 January 1701**
Died **Paris, France, 4 February 1774**

Charles-Marie de la Condamine is remembered for his participation in an expedition to Peru organized in 1734 by the Paris Academy of Sciences with the aim of providing a definitive verdict concerning the question of the shape of the Earth. La Condamine was the first son of a county family of low nobility. At 17, he joined the army and participated in combat in 1719, as part of a small contest against Spain. La Condamine left the army and established himself in Paris where he became interested in science. In December 1730, he obtained a position as adjunct chemist of the Paris Academy of Sciences. After travels devoted to adventure and study around the Mediterranean, la Condamine presented to the academy a communication that can be regarded as his first astronomical work: *Observations astronomiques et physiques faites dans un voyage au Levant en 1731 et 1732*.

At this time a Newtonian academician, **Pierre de Maupertuis**, promoted a fierce discussion concerning the true shape of the Earth. The starting point was the perceptible discrepancy between **Isaac Newton**'s theory and the geodetic measurements made in France by **Jean** and **Jacques Cassini**. The outcome was the decision to launch two expeditions, one to Lapland and the other one to the equatorial lands of the Vice-Kingdom of Peru, belonging to Spain. The Lapland expedition was led by Maupertuis. It produced its measurements in 1736 and 1737, and its results, when compared with measurements made in the French territory, were favorable to the Newtonian thesis. The Peru expedition was led by **Louis Godin**. La Condamine, **Pierre Bouguer**, and several naturalists and assistants joined him. It proceeded to America on 16 July 1735. Its French members and the Spanish sailors who accompanied them – Jorge Juan and Antonio de Ulloa – would return to Europe in stages, 10 years later.

The expedition report, published by Condamine as *Mesure des trois premiers degrés du méridien dans l'hémisphère austral* in 1751, confirmed Maupertuis' work. However, Condamine's report of his return journey through the Amazon, *Journal du voyage fait par ordre du roi a l'équateur*, also published in 1751, brought to its author significant fame in France; because of this, his name became firmly associated with the entire expedition.

Condamine's scientific contributions were published mainly in the *Histoire et Mémoires de l'Académie des Sciences de Paris*, from

1731 to 1761. They do not contain original astronomical discoveries. They provided data from geodesic measurements, latitude and longitude assessments, and meteorological observations from several places in America and Europe.

After Condamine's return to Europe, he also proposed a reform of the French and international metrological system. He recommended as a new universal standard the length of the pendulum beating seconds at the equator. To defend his proposal, after his American tour, he made several visits to different places in France and Italy to find out the length.

Condamine was also interested in other subjects such as smallpox inoculation and the improvement of education, publishing several works about them. He was elected a member of the French literary academy, the Académie française, on 29 November 1760, and remained a member up to his death – brought about by a hernia operation.

Antonio E. Ten
Translated by: *Roberto de Andrade Martins*

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Conon of Samos

Flourished **Alexandria, (Egypt), 3rd century BCE**

Conon was an Alexandrian court astronomer and also a friend of **Archimedes**. He collected eclipse records and studied conic sections. Conon added one of the few new northern constellations since **Eudoxus** (Coma Berenices). The tale of how this supposedly happened is well told by David Levy *et al.* A crater on the Moon is named Conon.

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Cooper, Edward Joshua

Born **possibly Dublin, Ireland, May 1798**
Died **Markree Castle near Colloney, Co. Sligo, Ireland, 23 April 1863**

Edward Cooper was a wealthy landowner who established a well-equipped private observatory on his estate at Markree Castle in County Sligo. Notable achievements at Markree were the mapping of over 60,000 stars around the ecliptic and the discovery of the minor planet (9) Metis in 1848.

Cooper was the second son of Edward Synge Cooper and his wife, Anne Verelst. His mother is said to have inculcated his early interest in astronomy, which was reinforced by visits to Armagh Observatory when he was a schoolboy in the town. He proceeded to Eton College and Christ Church College, Oxford, England, but left after only 2 years without taking his degree.

Cooper then traveled extensively, always taking portable instruments with him to find the latitude and longitude of the places he visited. In 1820 he went to Italy and Egypt, traveling as far as the second cataract on the Nile. He employed the landscape artist Bossi from Rome, and this resulted in a volume entitled *Views in Egypt and Nubia*, published privately in 1824. On his return, Cooper married Sophia (Sophie) L'Estrange on 1 January 1822. She bore him a son who lived only a few days and she, herself, died shortly afterward. He later married Sarah Frances Wynne of Hazelwood, Sligo, who bore him five daughters.

During 1824 and 1825 Cooper resumed his travels, visiting Denmark and Sweden and going as far as the North Cape in Norway. In 1824 he also started to make meteorological observations at Markree. Owing to his frequent absence, the initial records were somewhat irregular but from 1833 until his death in 1863 they were as good as any made elsewhere at that time.

After the death of his father in 1830, Cooper became manager of the estate and resolved to establish an astronomical observatory. In 1829 he had visited the optician Robert-Aglae Cauchoix in Paris, and by 1831 Cooper had purchased from him a lens of 13.3-in. aperture and 25-ft. focal length, the largest then in existence. He mounted the telescope on a temporary alt-azimuth stand of wood at Markree. News of this purchase soon reached **Thomas Robinson**, director of Armagh Observatory, and a cordial friendship ensued. Robinson persuaded Cooper to order a tube and equatorial mounting from **Thomas Grubb** in Dublin; this was Grubb's first major commission. Both the tube and the mounting were made of cast iron and weighed about 2,387 kg. The telescope was erected in April 1834 on a triangular pier of limestone blocks, and the polar axis was driven by a clockwork mechanism. There was no dome, but the lens was covered, and the observer was protected from the wind by a circular wall 16 ft. high and 36 ft. in diameter. Cooper originally intended to use the great refractor to observe double stars, but the image quality was not good enough because the lenses were not properly centered. Cooper also purchased a 5-ft. transit instrument by Edward Troughton, a meridian circle 3 ft. in diameter with a 7-in. objective by Ertel, and a 3-in. comet seeker also by Ertel. In 1851, Markree was authoritatively described in the *Monthly Notices* as "undoubtedly the most richly furnished of private observatories."

In March 1842, Cooper appointed Andrew Graham as an assistant, and the activity at the observatory increased dramatically. Graham found accurate positions of 50 telescopic stars within 2° of the pole, and he began to observe minor planets on the meridian. The accurate latitude and longitude of Markree were determined, the latter by means of rockets fired from a mountain between Armagh and Markree. The results were confirmed in August 1847 by the simultaneous observation of three meteors by Cooper at Killiney, County Dublin, and by Graham at Markree. In 1844 and 1845, Cooper and Graham toured France, Germany, and Italy taking the great refractor with them. Cooper sketched the Orion Nebula and detected independently, at Naples on 7 February 1845, a great comet (C/1844 Y1) that had already been observed in the Southern Hemisphere in 1844. He reported his observations of the annular eclipse of the Sun on 15 May 1836 to the Paris Academy of Sciences.

On 25 April 1848, Graham discovered the ninth minor planet with the Ertel comet seeker, and it was named Metis on the suggestion of Robinson. In order to facilitate the study of minor planets, Cooper initiated a program of observing stars along the ecliptic to 12th or 13th magnitude. This program continued until June 1860 when Graham resigned. The results were printed at government expense in four volumes with the title *Catalogue of Stars near the Ecliptic observed at Markree*. The volumes contained the approximate positions of 60,066 stars within 3° of the ecliptic, only 8,965 of which were already known. For this important contribution, the Royal Irish Academy awarded Cooper its Cunningham Gold Medal. He had been a member of the Academy from 1832 and was elected a fellow of the Royal Society in June 1853.

Cooper was a member of the Southern Telescope Committee set up by the Royal Society in 1852 in order to design and erect a large telescope in the Southern Hemisphere; this led eventually to the construction by Grubbs of the Great Melbourne Telescope. He was the Member of Parliament for County Sligo from 1830 to 1841 and again from 1857 to 1859. He was a kind and good landlord who combined a pleasant disposition with his varied accomplishments.

Ian Elliott

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Copeland, Ralph

Born **Woodplumpton, Lancashire, England, 3 September 1837**
Died **Edinburgh, Scotland, 27 October 1905**

Ralph Copeland served as Scotland's Astronomer Royal in Edinburgh.

Copeland's early education was completed at a grammar school in Kirkham, England. In 1853, he journeyed to Australia and spent the next five years in the colony of Victoria, working on a sheep ranch but also trying his hand at digging for gold in the Omeo district. Copeland's interest in astronomy arose during this period, and his desire to pursue an astronomical career led him back to his homeland. But Copeland was denied admission to Cambridge University. In turn, he apprenticed himself to a Manchester firm of locomotive engineers. Several coworkers assisted him in establishing a private observatory. Copeland married a first cousin, Susannah Milner, in 1859. She died, however, during the birth of their second child in 1866.

Copeland again determined to follow an astronomical career, and was admitted to Göttingen University in 1865. He gained practical experience at the university's observatory, under the direction of **Ernst Klinkerfues**. Copeland participated in the observation and reduction of stellar positions in two zones of declination between −2° and the Celestial Equator. These results, published as the *Göttingen Star Catalogue* (1869), were unsurpassed before 1900. During this period, Copeland assisted a German geodetical survey along the coast of Greenland and was awarded his Ph.D. in 1869 for a study of the orbital motion of the southern binary star, α Centauri.

After returning from Greenland, Copeland was appointed assistant astronomer (1871–1874) at the observatory of **William Parsons**, the Third Earl of Rosse, in Parsonstown, Ireland. In collaboration with the Fourth Earl, Copeland investigated the Moon's radiant heat. He was remarried to Theodora Benfrey of Göttingen; four more children were born to the couple. Copeland held a brief post at the Dunsink Observatory (Dublin, Ireland), observing reddish dwarf stars, before being appointed director of the Dunecht Observatory in Scotland (1876–1889), succeeding **David Gill.** There, Copeland observed comets and published their orbital elements in the observatory's *Circulars*. He observed the transits of Venus in 1874 (Mauritius) and 1882 (Jamaica). For three years (1881–1884), he coedited the journal, *Copernicus*.

Copeland's interests were certainly eclectic, and reflected many developments that arose across the span of his career. While trained in the traditional methods of positional astronomy, he readily pursued astrophysics and successfully made the transition from "old" to "new" astronomies, which few of his contemporaries accomplished. Copeland conducted important spectroscopic observations of comets as well as novae, emission nebulae, and Wolf–Rayet stars. He was among the first astronomers to exploit the astronomical seeing conditions found at high altitudes within the Andes Mountains of South America. Copeland's successful expedition was later instrumental in establishment of the Harvard College Observatory's field station at Arequipa, Peru. He was elected a fellow of the Royal Astronomical Society in 1874.

Upon the resignation of **Charles Smyth**, Copeland was appointed Astronomer Royal for Scotland in 1889 and concurrently Regius Professor of Astronomy at Edinburgh University. Copeland's principal task, however, concerned the selection of a new observatory site at Blackford Hill, and supervision of its construction. That institution was opened in 1896, but by then, Copeland's advancing age and declining health had begun to take their toll. Although he traveled abroad to observe three total solar eclipses (Norway, 1896; India, 1898; and Spain, 1900), the bulk of his astronomical work lay behind him. Copeland suffered an attack of influenza in 1901, from which he never fully recovered. His observations of Nova Persei (1901) were the last that he issued among the Edinburgh Observatory *Circulars*. He succumbed to heart disease.

Jordan D. Marché, II

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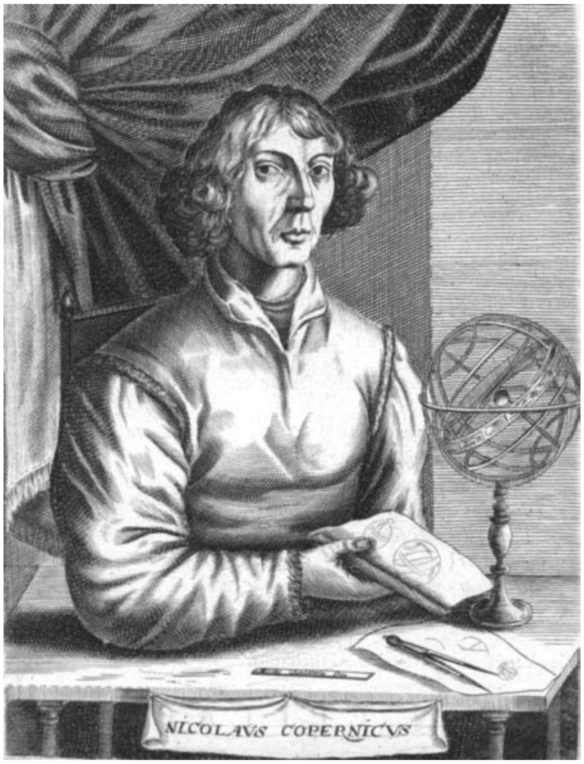
Copernicus [Coppernig, Copernik], Nicolaus [Nicholas]

Born **Toruń, Poland, 19 February 1473**
Died **Frombork, Poland, 24 May 1543**

Nicolaus Copernicus was the astronomer and cosmologist who "stopped the sun and set the earth in motion." His *De revolutionibus orbium coelestium* (On the revolutions of the heavenly spheres, Nuremberg, 1543) for the first time fully explained and supported a heliocentric system.

Copernicus' father, also named Nicholas, was a German-speaking merchant in the Hanseatic town of Toru, which by treaty in 1466 had become Polish territory. In the 16th century, Poland was a major political force in Eastern Europe, while the German area was a patchwork of duchies and principalities. By the 19th century the roles were reversed, and for a considerable period Poland scarcely existed as an independent country; much of the emerging scholarship on Copernicus was done by German authors. With the reestablishment of Poland after World War I, a bitter intellectual battle over Copernicus' ethnic origins took place, becoming especially shrill in the Nazi period. The spelling of the Copernicus family name became a political shibboleth, with the Germans advocating Coppernig or Koppernigk and the Poles Copernik. In the oldest autograph manuscript signed by Copernicus, he spelled his name Copernik, but throughout his life he appeared indifferent to orthography and sometimes spelled it Coppernicus. Nicolaus is the Latin form of his first name, used in his scholarly work.



When Nicholas was 10 his father died, and his maternal uncle Lucas Watzenrode, who was making great progress in ecclesiastical politics, became his guardian, sending him to Cracow University (1491–1495) and later to graduate study in Bologna, Italy (1496–1501). In 1495, soon after uncle Lucas became Bishop of Warmia, the northernmost diocese in Poland, he arranged for Nicolaus to become 1 of the 16 canons or managers of the Cathedral Chapter. Copernicus spent his life as a celibate churchman, but was never ordained as a priest. With permission from the canons he returned to Italy, to the University of Padua (1501–1503) where he studied medicine, but after 3 years, before he finished a medical degree, Copernicus went briefly to the University of Ferrara where he completed his examinations for the degree Doctor of Canon Law. Biographical data from these earliest years of his life are extremely sparse. For example, his birthday is known only because it appears in an early collection of horoscopes, and the fact that he studied civil law as well as canon (church) law in Bologna is attested solely by two words on a legal document where he served as witness.

Similarly, information about Copernicus's early interest in astronomy is fragmentary. His library included two 15th-century astronomy books with characteristic Cracow bindings, presumably acquired while he was an undergraduate student. In Bologna he boarded with the professor of astronomy, **Domenico da Novara**, and made at least one observation there reported in his *De revolutionibus.* Four decades later, Copernicus told his only disciple that around 1500 he had lectured on mathematics in Rome to a crowd of students and experts, but apart from a single sentence nothing more is known of the occasion.

On his return to Poland, Copernicus served as his uncle's personal secretary and physician, working in the Bishop's Palace in Lidzbark (Heilsberg) in the years 1503–1510. With his growing interest in astronomy, Copernicus elected not to try for advancement in church positions, although his fellow canons placed him in charge of the cathedral affairs several times. From 1510 his basic residence was in Frombork (Frauenburg), where Copernicus held quarters in a tower in the wall of the cathedral compound, although from 1516 to 1519 he served in Olsztyn (Allenstein) as administrator of the Cathedral Chapter's land holdings in that area.

Precisely when and where Copernicus formulated his heliocentric cosmology is unknown, but evidence points toward the period 1510–1512. A library inventory from 1514 for a Cracow scholar includes a manuscript pamphlet advocating a Sun-centered system, and when such a tract authored by Copernicus was rediscovered in 1878 in Vienna and another copy in 1884 in Stockholm, historians realized that they had recovered an early form of Copernicus' work. The anonymous and untitled document, given the name *Commentariolus* (or Little commentary), reveals neither the path to his discovery nor the motivations for his heliocentrism, although it expresses strong dissatisfaction with the Ptolemaic equant, which Copernicus believed violated the principle of constructing astronomical explanations from uniform circular motion. Of course, the radical heliocentric arrangement and the mobility of the Earth are quite independent of this ancient principle.

When the full Latin text of the *Almagest* was finally printed in 1515, Copernicus must have realized how comprehensive any treatise hoping to compete with **Ptolemy**'s would have to be, and he must have understood as well that he would require critical observations over a fair number of years to confirm or reestablish the parameters of the planetary orbits. Consequently, for the next 15 years Copernicus bided his time, making the occasional required observations. In *De revolutionibus* he used 27 of his own observations and 45 gleaned from the *Almagest.* Copernicus presumably made many more observations, although only a dozen more are documented prior to 1530. Obviously, he made no attempt to observe on a daily or weekly basis, but only at critical times when the geometrical configurations of the planets lent themselves to the determination of the parameters. Copernicus was not a particularly accurate observer, and one of his Mars observations erred by more than 2°. His earliest observation reported in *De revolutionibus* is the occultation of Aldebaran that he observed on 9 March 1497 and the latest is one of slow-moving Saturn, made in 1527. The geometrical configuration for Venus was unfavorable in the 16th century, so Copernicus reported only one modern observation of that planet, and none of his own for the planet Mercury.

Throughout the 1520s and 1530s, Copernicus attended to a great variety of Cathedral Chapter business, which included organizing defenses against the encroachments (1520–1525) of the Teutonic knights who occupied the Prussian territory to the east, and framing documents relating to currency reform, where he anticipated Thomas Gresham in formulating the law that bad currency drives out the good.

Copernicus continued to labor on his astronomical treatise, which he had already promised in his *Commentariolus*, but he showed persistent reluctance concerning publication despite pressure from his fellow canons (who scarcely understood the technical aspects of his work), including his best friend, Tiedemann Giese. This situation began to change in 1539 when an enthusiastic young mathematician from the Lutheran University of Wittenberg, **Rheticus**, came for a visit that eventually extended more than 2 years. Copernicus allowed Rheticus to publish a "first report" on the heliocentric system (*Narratio prima,* Gdansk, 1540), and the favorable reception of that brief account finally encouraged Copernicus to release his manuscript for publication, even though many details still lacked the final polish he desired. In 1541, Rheticus returned to Wittenberg with a copy of the manuscript, and the following spring took it to Nuremberg where there was a printer, Johannes Petreius, with an international distribution that could sustain such an undertaking. As the printing progressed, Copernicus received the sheets, carefully marking the errors for inclusion on an errata leaf. The printing of *De revolutionibus* was completed in April 1543, and according to a letter from Giese, Copernicus, who had meanwhile suffered a stroke, received the final pages on the very day he died.

Copernicus presented his new heliocentric cosmology in the first 4% of the treatise, giving his counterarguments to the ancient opinion concerning the immobility of the Earth, and stressing his two most compelling evidences in favor of the Sun-centered arrangement of the planets. First, the heliocentric system provided a natural explanation for the so-called retrograde motion of the planets, and, second, the unification of the orbits automatically placed the fastest planet, Mercury, closest to the Sun, and lethargic Saturn the farthest, with the Earth's annual period falling nicely between those of Venus and Mars. As he wrote in the soaring cosmological Chapter 10 of Book I, "We find in this arrangement a marvelous common measure of the universe and a sure harmonious connection between the motions and sizes of the orbs, which can be found in no other way." The common measure was the Earth–Sun distance, which provided a measuring stick for the entire system, whose spacings were now linked together. The harmonious connection would find a mathematical expression in **Johannes Kepler**'s third or harmonic law, which in turn gave the clue that the gravitational force from the Sun diminished by the inverse square of the distance.

Finally, Copernicus offered a solid kinematic basis for the phenomenon of precession of the equinoxes, which he described as the conical motion of the Earth's axis.

The remaining 96% of *De revolutionibus* comprised trigonometric rules and tables, a lengthy star catalog adapted from Ptolemy, a detailed determination of planetary parameters from both ancient and modern observations, and tables from which predictions could be made. Considerable attention was given to the use of small epicyclets to substitute for Ptolemy's equant mechanism, in general using a single epicyclet and eccentric orbital circle for each planet, as opposed to the double epicyclet and concentric orbital circle proposed in his earlier *Commentariolus*. His mechanisms scored a major success with respect to the Moon; in Ptolemy's formulation the Moon's distance varied by more than a factor of two, contrary to observations, and the Copernican scheme considerably ameliorated (but did not entirely eliminate) this problem. Because he relied so heavily on Ptolemy's observations, the accuracy of his system, which was essentially a geometrical transformation of the geocentric arrangement, was not substantially higher than the earlier tables.

When *De revolutionibus* was being printed, Petreius' proofreader, **Andreas Osiander**, added an anonymous introduction saying that the new cosmology was merely hypothetical, neither necessarily true or even probable. When Giese saw it, he took great exception, saying it was contrary to Copernicus' beliefs, and he complained to the Nuremberg city council but to no avail. While Osiander has been much castigated for his action, it did have the desired effect of sheltering the book from religious critics. In several presentation copies, Rheticus crossed off the Osiander introduction with a red crayon, and also the words *orbium coelestium* in the title; while it is hard to see why "heavenly spheres" was objectionable, apparently Copernicus preferred the shorter title, and today most scholars refer to the book simply as *De revolutionibus* (or The Revolutions).

Astronomers of the 16th century almost unanimously withheld judgment of the heliocentric proposal in the absence of any physics compatible with a moving Earth and any physical demonstrations or proofs of the Earth's motion; Kepler and **Galileo Galilei** were two conspicuous exceptions. On the other hand, the idea of replacing the equant with an epicycle, ultimately a scientific dead end, was received with widespread enthusiasm, and Copernicus was reckoned the modern Ptolemy. Eventually, of course, it was the heliocentric arrangement that paved the way for the concept of universal gravitation and Newtonian physics. Subsequently he was praised as the Father of the Scientific Revolution.

Owen Gingerich

Alternate name

Koppernigk, Nicolaus [Nicholas]

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Cornu, Marie Alfred

Born **Châteauneux near Orléans, Loiret, France, 6 March 1841**

Died **La Chansonnerie near Romorantin, Loir-et-Cher, France, 12 April 1902**

French physicist Alfred Cornu is remembered for his precise determination of the speed of light, and for work in physical optics (especially on diffraction theory and ultraviolet spectroscopy). He was the son of François Cornu and Sophie Poinsellier.

Cornu attended the École Polytechnique in Paris between 1860 and 1862, finishing second in his class. Upon graduating, he obtained his mathematics *Licence* and his physics *Licence* the following year. Cornu was appointed *répétiteur* (demonstrator) at the École Polytechnique in 1864. He also attended the École des Mines (1862–1865), becoming an engineer of mines in 1866. Cornu then obtained his doctorate in the physical sciences in 1867 with a thesis on crystalline reflection and was subsequently appointed professor of physics at the École Polytechnique, a post he retained until his death. Cornu was active at the Bureau des longitudes from 1886, writing articles on physics and astronomy for its publication, the *Annuaire*, and looking over the Nice Observatory under the bureau's administration. In 1873, Cornu married Alice Vincent; the couple had at least one son.

Cornu began his career as a *protégé* of **Hippolyte Fizeau**, whose measurement of the speed of light he repeated with high accuracy. For this accomplishment, he was awarded the La Caze Prize of the French Académie des sciences (1877) and the Rumford Medal of the Royal Society of London (1878). Cornu became a central figure in late 19th-century French physics. His subsequent research exemplifies that community's interest in the study and construction of scientific instruments and the precise measurements allowed by them (metrology). **Jules Poincaré** wrote of Cornu that "there are few areas of physics in which he failed to push back the limits of precision."

Cornu's principal interests were in physical and instrumental optics and their applications to astronomy. In writing about terrestrial measurements of the speed of light, Cornu noted that "[f]rom now on, the roles are reversed: physics now supplies astronomy with one of the most precious constants, since it determines the absolute unit for measuring celestial distances." He studied optical interference, developed methods for determining optical constants and the curvature of lenses, and studied anomalies of diffraction gratings. His geometric representation of the intensity plots in Fresnel diffraction theory is known as the Cornu spiral.

Cornu conducted research in spectroscopy, especially charting the solar ultraviolet spectrum and helping to complete **Anders Ångström**'s map of solar spectral lines. He examined atmospheric absorption lines using the Doppler effect, investigated the Zeeman effect, and studied line reversals. In addition, the photometry of polarized light, the mean density of the Earth (using **Henry Cavendish**'s method), and meteorological phenomena attracted Cornu's attention. He devised a photometric method for observing the eclipses of Jupiter's satellites, and prepared expeditions to observe the transits of Venus (1874 and 1882).

Metrology remained a central concern for Cornu. A member of the Comité International des Poids et Mesures (and its president in 1901), he worked to develop the centimeter-gram-second [CGS] system of units. For the Section française of the Commission du Mètre, Cornu contributed to the elaboration of national and international meter prototypes, introducing, for instance, a particular method of polishing meter bars and making comparisons of the mètre des Archives with the international standard. He also worked on the electric synchronization of clocks.

Cornu was a delegate to the Association Géodesique Internationale and the Astrographic Congress (1887). He was a cofounder and later president (1896) of the Société française de physique, as well as president of the Congress of Physics that took place in Paris in 1900. He was appointed an associate editor of the *Astrophysical Journal*. Cornu also served as president of the Société Astronomique de France.

Cornu was made *Chevalier* of the *Légion d'honneur* in 1878 (an *Officier* in 1890), as well as *Officier* of the *Ordre de Léopold* (1890). He was awarded honorary doctorates by the University of Oxford (1895) and the University of Cambridge (1899).

Charlotte Bigg

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Cosmas Indicopleustes

Flourished **Alexandria, (Egypt), 6th century**

After sailing to Ethiopia and India on trading voyages, Cosmas Indicopleustes retired to the monastery of Saint Catherine in the Sinai Desert, where he wrote cosmographical and theological treatises in Greek, of which only his *Christian Topography* and a few fragments of other works have survived. Both elements of the name Cosmas Indicopleustes appear to be descriptive and may be monastic; Cosmas may be derived from his account of the Universe (*cosmos* in Greek) and Indicopleustes ("Indian sailor" in Greek) from the voyages to India that he mentions in his *Christian Topography*.

Cosmas included a number of autobiographical details in the *Christian Topography*. He wrote that he suffered from continual ill health in Alexandria, and that he received a Christian education there that was based on the scriptures and the teachings of the Nestorian Patricius. He claimed that this education left him ignorant of the rhetorical techniques of the pagans. The deficiencies of his education are apparent from Photius' judgement on his "low" style, from his confused account of the myth of Atlantis as related by Critias in **Plato**'s *Timaeus* and *Critias*, and from his reliance on Josephus for earlier sources of information mentioned at the beginning of Book 12.

Cosmas himself stated that he voyaged over the Mediterranean Sea, the Red Sea, and the Persian Gulf for the purpose of trading. In the early years of the reign of the Byzantine Emperor Justin (*circa* 520), he also traveled to Ethiopia where he transcribed a Greek inscription from the throne of the King of Axum at the request of the Governor of Adoulis, thus preserving this valuable document for posterity. In Ethiopia, Cosmas saw some of the more unusual animals, such as the rhinoceros and the giraffe. His description of the latter leaves no doubt that he himself saw the animal, and he was careful to say that he had not personally seen a unicorn. Cosmas probably reached India, but his information about Taprobane (Sri Lanka) may be only secondhand. Nevertheless, Cosmas provided unique information about the politics (the kingdom was divided north and south), economics (Taprobane was an *entrepôt* between East and West), and religion (there was a community of Persian Christians there) of the island.

Cosmas probably belonged to the Nestorian sect: his teacher Patricius was a Nestorian. He did not list Nestorians as a heretical sect. Finally, he praised the establishment of the Christian church in India and the islands in the vicinity of India, which was carried out by Nestorians.

In his *Christian Topography*, composed between 535 and 547–550, Cosmas set out to disprove the pagan, especially Ptolemaic, theory that the Earth is a sphere around which other spheres containing the planets and constellations revolve, and to refute those Christians, such as Saint Basil, who tolerated this idea of the Universe. He was particularly opposed to the theory of the antipodes, arguing from common sense that it was impossible for people to stand with their heads pointing down and for rain to fall upward. Instead, Cosmas followed Christian doctrine (possibly originating in Syria) according to which the Universe is shaped like the tabernacle constructed by Moses. Inspiration for this model may ultimately have been derived from Saint Paul's letter to the Hebrews, concerning the symbolism of the tabernacle. The veil that divided the tabernacle into two represented the division of the heavens and the Earth by the firmament (*stereoma*). The angels and men live below the firmament, but Christ ascended to heaven above it. The table with unleavened showbread in the tabernacle stood for the Earth surrounded by the ocean. (Both tabernacle and Earth were rectangular, twice as long as they were wide.) According to Cosmas, who here relied on his understanding of Hellenistic geography, the Earth is penetrated by four gulfs: the Mediterranean, the Persian, the Arabian, and the Caspian. The ocean is unnavigable, hence the anecdote in which Cosmas relates that during a voyage to Ethiopia passengers and crew of the ship in which he was sailing ordered the helmsman to turn about as they feared that they would be swept into the circumambient ocean and lost. Turning to biblical authority again, Cosmas related that the ocean is in turn surrounded by another earth in which paradise was physically located (although it was not possible to sail there because of the ocean) and where man had lived until Noah's flood. Four rivers somehow flow through the ocean from this paradise, the Phison (the Indus or Ganges), the Gihon (Nile), and the Tigris and Euphrates. The heavens resemble a vault and descend to the Earth in four walls. An original element in this scheme is the idea that the Earth has an immense mountain in the northwest, behind which the Sun disappears at night. The different length of days and nights is explained by the varying height at which the Sun circles this mountain. The Sun itself is only the size of two of Earth's climates or zones, such as those between Alexandria and Rhodes, and Rhodes and Constantinople. The seven planets are represented by the seven flames of the Jewish candelabrum and are set in motion by the angels.

Cosmas represents a step backward in the history of astronomy and cosmology, but he is nevertheless significant because he illustrates the powerful influence of ideology in the construction of models of the Universe. His drawings and illustrations are of interest in the history of cartography and artistic miniatures. The first-hand historical information he provides for ancient Ethiopia, India, and neighboring islands is unique.

John Hilton

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Cosserat, Eugène-Maurice-Pierre

Born **Amiens, Somme, France, 4 March 1866**
Died **Toulouse, Haute-Garonne, France, 31 May 1931**

In addition to his long tenure as director of the Toulouse Observatory, Eugène Cosserat was noted for his contributions as a geometer, and in analytical mechanics, particularly in the theory of elasticity and surface deformation. Educated first in Amiens, Cosserat entered the École Normale Supérieure [ENS] in Paris at the age of only 17. He was appointed to the observatory in Toulouse in 1886 after his graduation from ENS. At Toulouse, Cosserat participated in an observatory routine that was typical of 19th-century professional astronomy, particularly in France, and included many hours of meridian observations and reductions of stellar and planetary positions. In the first part of his career he also made physical observations of double stars, planets, and comets.

Cosserat's main interests, however, were mathematical and theoretical rather than practical astronomy. His doctoral dissertation, defended in 1888 or only 2 years after his graduation from ENS, considered infinitesimal properties of space generated by circles, an extension of Julius Plücker's concept of generation by means of straight lines. Cosserat's first appointment on the faculty of science at the University of Toulouse, in 1896, was as professor of differential calculus. It was not until 1908 that Cosserat was appointed to the chair of astronomy at Toulouse, thereby becoming director of the observatory. He held that position for the rest of his life. Described as "a reserved, kindly man and a diligent worker," Cosserat was one of the moving forces in the University of Toulouse faculty for 35 years.

An international project, the *Carte du Ciel*, formed the principal work of the Toulouse Observatory during Cosserat's tenure. Cosserat was a participant in the formulation of the plans for this undertaking. Under his personal supervision, the observatory staff completed their assigned zone (+10° to +5°) of meridian observations, the exposure of 1,080 photographic plates, and the computations necessary to reduce the results to a catalog. The published catalog and map that resulted from this effort represented 10% of the completed work in the *International Carte du Ciel*, an effort involving a total of 24 observatories around the world. The proper motions of stars formed another active area of Cosserat's work.

In his later theoretical work, Cosserat studied the deformation of surfaces, which led him to a theory of elasticity in collaboration with his brother François, the chief engineer of the French service for bridges and roads. Cosserat also worked on an extension of mechanics, based on Euclidean laws, into an original and coherent theory. However, his work in this area, although important at the time, was overtaken by the theory of relativity and other advances in theoretical physics.

Although he was not living in Paris, Cosserat was elected to the Académie des sciences in 1919 and, 4 years later, to the Bureau des longitudes as a nonresident, corresponding member of these organizations.

Ednilson Oliveira

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Costa ben Luca

➔ **Qusṭā ibn Lūqā al-Baʿlabakkī**

Cotes, Roger

Born **Burbage, Leicestershire, England, 10 July 1682**
Died **Cambridge, England, 5 June 1716**

Roger Cotes was the editor of the second edition of **Isaac Newton**'s *Principia*. An innovative educator and popularizer, he brought astronomy, experimental philosophy, and Newtonian physics to half a generation of Cambridge undergraduates. After his early death, Newton said of him "Had Cotes lived we might have known something."

The second son of Reverend Robert Cotes, rector of Burbage, and Grace, daughter of Major Farmer of Barwell, Cotes was sent to Leicester School. His mathematical ability induced his uncle, Reverend John Smith, to direct his education in his home. He later attended Saint Paul's School in London. Cotes matriculated at Trinity College, Cambridge, in 1699, taking his BA in 1702 and his MA in 1706. It is likely that he attended the astronomical lectures of the Newtonian Lucasian Professor **William Whiston** and possibly the first of Whiston's lectures on Newton's *Principia* (1704). Cotes was elected a fellow of Trinity College in 1705.

As an undergraduate, Cotes impressed **Richard Bentley**, master of Trinity, with his abilities in astronomy and mathematics. Bentley, who early on was keen to establish Trinity College as a leader in the teaching of natural philosophy, introduced Cotes to Newton and his successor Whiston. With support from both Bentley and Whiston, Cotes was elected the first Plumian Professor of Astronomy and Experimental Philosophy in October 1707.

Bentley spearheaded a subscription to build the observatory at Trinity, although it was not completed in Cotes' lifetime. Cotes was assigned rooms in the observatory, which he occupied with his cousin and assistant Robert Smith. The observatory was equipped with astronomical instruments, including a fine brass sextant with a radius of 5 ft., a transit instrument, and a pendulum clock (the latter donated by Newton). Cotes delivered his lectures in the observatory and carried out astronomical observations from its viewing platform.

Beginning in May 1707, Cotes and Whiston delivered a course of hydrostatic and pneumatic experiments, with Cotes lecturing on hydrostatics and Whiston on pneumatics. It was the first course of its kind at Cambridge, and it focused on the replication of set piece experiments such as Boyle's air-pump experiments. Among those who attended were Stephen Hales and **William Stukeley**, both of whom became prominent Newtonians. After Whiston's expulsion for heresy in 1710, Cotes continued to deliver the lectures on his own.

In 1714, Cotes published a paper in the *Philosophical Transactions* entitled "Logometria." The first part of this paper deals with methods for the calculation of Briggsian logarithms. The remainder of the paper applies integration to problems concerning quadratures, the lengths of arcs, surface areas of revolution, and atmospheric density. This was the only writing by Cotes that was published independently in his lifetime.

The total solar eclipse of 22 April 1715 afforded Cotes the opportunity to carry out detailed observations from the observatory. He was able to observe the occultation of three sunspots and the precise conclusion of the period of total darkness and the eclipse. These results were communicated to the *Philosophical Transactions* by **Edmond Halley**. Cotes also supplied Newton with a detailed sketch of the Sun's corona. Cotes' observations of the aurora borealis on 6 March 1716 was published in the *Philosophical Transactions* by his cousin in 1720.

As Plumian Professor, Cotes also acted as a commissioner of the Board of Longitude, created in 1714 to administer a £20,000 prize for the discovery of an accurate method of determining longitude at sea. Cotes was named a fellow of the Royal Society in 1711; he took holy orders in 1713. Cotes never married.

At Bentley's suggestion, in 1709 Cotes became the editor of the second edition of Newton's *Principia*, which led to a voluminous correspondence between Cotes and Newton during the next 3½ years. Cotes' enthusiasm helped to energize the author. He was well suited for the task, given his knowledge, his ability to offer advice to Newton, and his diplomatic skills.

Cotes' offer to write a preface was accepted by the author. Cotes' chief agenda is the defense of Newton's demonstration of universal gravitation, which had been attacked for reintroducing occult qualities into natural philosophy. Cotes begins by rejecting both ancient Greek and Cartesian approaches to understanding nature. The Newtonian method is one that begins with experiment and observation. Cotes speaks of this approach as "a twofold method, analytic and synthetic." This, he elaborates as follows: "From certain selected phenomena [the Newtonians] deduce by analysis the forces of nature and the simpler laws of those forces, from which they then give the constitution of the rest of the phenomena by synthesis."

Cotes writes eloquently about the power of gravity extending not only to the planets but also to comets outside the planetary system. He concludes that "the earth and the sun and all the celestial bodies that accompany the sun attract one another." It is at this point that he offers his famous argument about the same power of gravity operating in America as in Europe: "For if gravity is the cause of the fall of a stone in Europe, who can doubt that in America the cause of the fall is the same? If gravity is mutual between a stone and the earth in Europe, who will deny that it is mutual in America?" Cotes goes on to declare that "[a]ll philosophy is based on this rule, inasmuch as, if it is taken away, there is then nothing we can affirm about things universally." In response to Cartesians, Cotes affirms, "It is the province of true philosophy to derive the natures of things from causes that truly exist, and to seek those laws by which the supreme artificer willed to establish this most beautiful order of the world, not those laws by which he could have, had it so pleased him."

In this declaration of empiricist methodology is a hint at the natural theology that comes at the end of the preface. Cotes ventures into natural theological apologetics, exclaiming that "[h]e must be blind who does not at once see, from the best and wisest structures of things, the infinite wisdom and goodness of their almighty creator; and he must be mad who refuses to acknowledge them." Cotes then speaks particularly about the role of Newton's *magnum opus* in promoting natural theology: "Newton's excellent treatise will stand as a mighty fortress against the attacks of atheists; nowhere else will you find more effective ammunition against that impious crowd." This confirms that he agreed with Newton's apologetics that Newton, in the General Scholium, added to the *Principia*'s second edition.

After Cotes' death, his cousin Smith succeeded him to the Plumian Professorship and edited and published Cotes' mathematical writings as *Harmonia mesurarum* (1722). The first part of this volume consists of a reprint of Cotes' "Logometria." The second part is made up of elaborations of Newton's fluxions and contains the theorem subsequently known as Cotes's theorem. The third part is a collection of Cotes' other writings on mathematics, including a paper on Newton's differential method that contains an articulation of what has come to be known as the Newton–Cotes formula. Like Newton, Cotes appears to have preferred geometry to analysis in the presentation of his mathematics. Smith also published Cotes' hydrostatical and pneumatical lectures in 1738.

Stephen D. Snobelen

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Couderc, Paul

Born **Nevers, Nièvre, France, 15 July 1899**
Died **Paris, France, 5 February 1981**

Paul Couderc is best known as a writer of approximately fifteen popular works on astronomy.

Couderc, son of Jean Couderc and Marguerite Chastang, attended *lycées* (schools) at Nevers and Dijon, before transferring to the École Normale Supérieure at Paris, where he earned a doctorate in mathematical sciences. In 1926, he married Blanch Jurus.

Couderc was the first to explain the phenomena of light echoes observed around Nova Persei (1901) and especially their apparent, although not actual, superluminal expansion (*i. e.*, travel at speeds faster than that of light). Although receiving little attention at the time, Couderc's geometrical explanation was later applied to an understanding of supernovae, quasars, and even γ-ray bursts.

Couderc's career included professorships of mathematics in *lycées* at Chartres (1926–1929), Montaigne, Charlemagne, and Janson-de-Sailly at Paris (1930–1944). He was appointed an astronomer (and lecturer) at the Observatoire de Paris in 1944, from which he retired in 1969. The following year, he received the title of honorary astronomer.

Couderc's works included *L'Architecture de l'Univers* (1930), *Parmi les étoiles* (Among the stars) (1938), *La Relativité* (1942), *L'Expansion de l'Univers* (1952), and *Histoire de l'Astronomie* (1974). Many of these works were later translated into English and republished. Couderc played a significant role in the founding of the Planétarium du Palais de la Découverte at Paris, which opened in 1952.

Couderc served as secretary-general of the French National Committee for Astronomy and as vice president of the Sociéte Astronomique de France. He was a member of the International Academy of Astronautics and a founding member of the Association of Scientific Writers of France. Couderc was appointed an *Officier de la Légion d'honneur* and received the United Nation's (UNESCO) Kalinga Prize (1966/1967).

Jordan D. Marché, II

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Cousins, Alan William James

Born **Cape Town, South Africa, 8 August 1903**
Died **Cape Town, South Africa, 11 May 2001**

Throughout his astronomical career, Alan Cousins showed an almost obsessive interest in stellar photometry, and specifically in the photometry of standard stars.

Cousins's father, who emigrated from Britain to South Africa, became a senior civil servant, at one time Secretary of Labour. His mother was a daughter of Sir James Murray, first editor of the *Oxford English Dictionary*. Cousins was the eldest of four children and moved to Pretoria with his family where he completed his later schooling. At the University of the Witwatersrand in Johannesburg, Cousins studied mechanical and electrical engineering and graduated with a B.Sc. in 1925, being awarded the vice chancellor's prize for best student. In 1938, he married Alison Mavis Donaldson, and they had two children.

Cousins worked for some 20 years in the electrical utility industry, during which time he made numerous observations of variable stars. He was then offered a post at the Royal Observatory (later the South African Astronomical Observatory [SAAO]) in Cape Town, where Cousins spent the remainder of his life. He was awarded a Ph.D. by the University of Cape Town in 1954 for a thesis entitled "Standard Magnitude Sequences in the E Regions."

Cousins was elected president of the Astronomical Society of Southern Africa in 1944/1945 and was awarded the Gill Medal of the Society in 1963 for his photometric work. He was elected a fellow of the Royal Astronomical Society in 1941 and received the Society's Jackson Gwilt Medal in 1971, "in recognition of fifty years of distinguished service to observational stellar astronomy." From 1967 to 1970, Cousins served as president of Commission 25 (Stellar Photometry) of the International Astronomical Union [IAU].

During his early years at the Royal Observatory, Cousins continued work with the Fabry method of photographic photometry that he had begun as an amateur. In the late 1950s, when photomultiplier tubes became commonplace, Cousins saw the opportunity of making more precise measurements of fainter stars. He used his background in electrical engineering to good effect, constructing the required power supplies and recording equipment, and was largely responsible for introducing photoelectric photometry into South Africa. Together with Richard H. Stoy, Cousins produced a major catalog of the magnitudes of standard stars in the nine Harvard E regions, centered at −45° declination. These measurements provided a fundamental basis for Southern Hemisphere photometry, using the Harold L. Johnson UBV standards. With the growth of astronomy in the Southern Hemisphere, concerns were expressed about the homogeneity of northern and southern photometric systems. In response to a proposal by IAU Commission 25, Cousins established a set of bright fundamental reference stars in the equatorial band, which permitted the two systems to be linked accurately.

At the age of 73, Cousins retired from the full-time staff at SAAO but continued in a consultative role, still working full time. He continued to make observations with an 18-in. reflector in Cape Town into his early 90s, and worked in his office at SAAO every day. During this period, Cousins exploited a newly available red-sensitive photomultiplier tube to set up a photometric system aimed at providing information on the energy distribution of red stars. The V(RI)c system, originally based on one devised by **Gerald Kron** but now known as the Cousins system (or sometimes, "Kron-Cousins"), allows standardized, broadband, Johnson–Cousins UBVRI measurements of stellar flux from near-ultraviolet to near-infrared wavelengths. Photometric data of this kind are fundamental to current astronomical research.

Throughout his scientific career, Cousins showed a deep regard for careful measurement. He emphasized the importance of data treatment and of accurate assessments of observational errors. His publications span a remarkable 77 years; the first was written as an undergraduate student, while the last, which dealt with the effects of atmospheric extinction in the ultraviolet, appeared in print on the very day of his death. Cousins made a major contribution to ensuring a sound foundation for astronomical photoelectric photometry.

John Menzies

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Cowell, Philip Herbert

Born **Calcutta, (India), 7 August 1870**
Died **Aldeburgh, Suffolk, England, 6 June 1949**

English mathematical astronomer Philip Cowell was the second of five children of Herbert Cowell and the former Alice Garrett. He was educated in England, first at the private school at Stoke Poges and then in 1883 at Eton as a King's scholar. At an early age, Cowell showed unusual mathematical ability, entering Trinity College in 1889 and graduating as senior wrangler in 1892. In 1896, he was appointed to the newly created position of second chief assistant at the Royal Greenwich Observatory. While he had no aptitude or interest in astronomical instruments, Cowell excelled in the reduction and analysis of astronomical observations. In 1910, he was appointed superintendent of the Nautical Almanac Office and continued the direction of this work until his retirement in 1930. Cowell died of cardiac asthma. In 1901, he married Phyllis Chaplin who died in 1924. They had no children.

For his early work on the motion of the Moon, Cowell was elected a fellow of the Royal Society in 1906 and for his lunar work and subsequent research, which led to the Cowell method of numerical integration, he was given an honorary Doctor of Science degree at Oxford (1910) and the Gold Medal of the Royal Astronomical Society (1911).

Cowell's early research work concerned the Moon's motion and the comparison of lunar observations with the Moon's position predictions provided by analytic theories. He made advances toward understanding the motion of the Moon's orbital node, confirmed the basic correctness of the existing theories, and conducted a study on the secular acceleration of the Moon's mean longitude from a study of ancient eclipse records. Lunar tidal forces acting upon the Earth slow its rotation, and, to conserve angular momentum, the Moon spirals away from the Earth. Cowell showed that small corrections to the lunar node could explain the ancient eclipse observations whereas others the had assumed that corrections to the lunar longitude were required. That is, Cowell showed that a portion of the Moon's secular mean longitude could be apparent rather than real.

Cowell is perhaps best known for the computational technique he developed wherein an object's perturbed heliocentric position in space can be computed directly at each time step. Variations of this technique are still widely employed in computing the motions of Solar System bodies using high-speed computers. It is ironic that Cowell, who always did his computations by hand, developed a computational technique that is ideally suited for electronic computing machines.

Together with **Andrew Crommelin**, Cowell employed his numerical integration technique to determine the motion of the eighth satellite of Jupiter that had been discovered in 1908. Because the solar perturbations amounted to about 10% of Jupiter's central acceleration, Cowell could not utilize the analytical perturbation techniques that were then popular. The motion of the satellite was determined to be retrograde about Jupiter. As such it was the second retrograde satellite found after Phoebe, a satellite of Saturn.

In an effort to follow the motion of comet 1P/Halley and predict its upcoming perihelion passage in 1910, Cowell and Crommelin applied Cowell's method to the motion of comet Halley and predicted its perihelion passage time as 1910 April 17.1. This date turned out to be 3 days early and, in hindsight, this is what should have been expected since later work showed that the icy comet's rocket-like outgasing effects lengthen its orbital period by an average of 4 days per period. In an earlier work published in 1907, Cowell and Crommelin made the first attempt to integrate the motion of comet Halley backward into the ancient era. Using a variation of elements method, rather than the direct numerical integration technique used later, they accurately carried the comet's motion back in time to 1301 by taking into account perturbations in the comet's period from the effects of Venus, Earth, Jupiter, Saturn, Uranus, and Neptune. Using successively more approximate perturbation techniques, they then carried the comet's motion back to 239 BCE. At this stage, their integration was in error by nearly 1.5 years in the comet's perihelion passage time, and they adopted a time of 15 May 240 BCE, not from their computations but from a consideration of the ancient Chinese observations themselves.

Toward the end of his career, Cowell became disappointed that he was not appointed the Plumian Professor of Astronomy at Cambridge when the position became open in 1912 and was again disappointed the following year when he failed to be appointed to a Cambridge Professorship of Astronomy and Geometry. It was **Arthur Eddington** who was elected to succeed Sir **George Darwin** in the Plumian chair of astronomy and experimental philosophy in 1913.

Donald K. Yeomans

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Cowling, Thomas George

Born **Walthamstow, (London), England, 17 June 1906**
Died **Leeds, England, 16 June 1990**

English mathematician and theoretical astrophysicist Thomas Cowling gave his name to a model of stellar structure in which all of the energy is released very close to the center and to a theorem relevant to the generation and structure of the magnetic fields of the Earth and Sun. However, the part of his work that has the strongest resonance down to the present is the classification of vibrational modes in the Sun or other stars into *p* (where pressure is the restoring force) and *g* (where gravity is the restoring force) modes, separated by a fundamental radial oscillation, all of which have now been seen and which provide vital information on the deep interiors of the Sun and other stars.

Cowling was the second of four sons of Edith and George Cowling, an engineer with the post office, who brought home a large horseshoe magnet that may well have contributed to his son's lifelong interest in magnetism. The family members were all lifelong active Baptists. Cowling married Dorris Marjorie Moffatt in 1935 and was survived by her and their three children.

Cowling graduated from a county-supported grammar school in 1923 and won a scholarship to Brasenose College, Oxford, where he earned a first class degree in mathematics in 1927 and a teaching diploma in 1928. This delayed his start in research toward the Ph.D. (1930) by 1 year, so that he had the opportunity to become the first Oxford student of **Edward Milne**. Milne made him work on the structure of stellar atmospheres. Among the results was the conclusion that work by **Sydney Chapman** purporting to show that the magnetic field of the Sun could not extend out very far was simply wrong. The Sun must have open field lines extending very far out (far beyond the orbit of the Earth). It is a tribute to Chapman that he reacted to this by offering Cowling his first job as a demonstrator in the mathematics department at Imperial College, London.

Cowling spent his entire career in university mathematics departments: Swansea, 1933–1937; Dundee, 1937/1938; Manchester, 1938–1945; Bangor, 1945–1948; and Leeds, 1948–1970, the first three in lectureships, the last two as professor. He guided very few research students or fellows; only Eric Priest (a solar physicist) and Leon Mestel (a mathematically inclined astrophysicist particularly interested in magnetic fields) remained in astronomy.

A number of Cowling's calculations were of considerable importance at the time. These included a demonstration that magnetic field lines must be frozen into an ionized gas (1932). A more developed version of it was later published by **Hannes Alfvén**, whose relationship with Cowling was one of mutually respectful criticism.

Cowling demonstrated in 1934 that an axisymmetric field cannot be maintained by dynamo action. This result bares the name of "Cowling antidynamo theorem" and prevents axisymmetric approaches to describe the magnetic field of the Earth and Sun.

Another Cowling demonstration showed that the lowered temperatures of sunspots must be maintained by magnetic fields connected with the solar interior (1935). In the Cowling model for stellar structure, energy generation is confined to the extreme center. A core with convective energy transport and an envelope with radiative energy transport are now known to describe the conditions of hydrogen-burning stars of more than about 1.5 solar masses, which are powered by the CNO cycle.

Cowling considered the possible runaway pulsational instability of stars with centrally concentrated energy generation (1935). He showed that convection would take over before the instability got out of hand except in very massive stars. Such stars are now known to display such instabilities as luminous blue variable or Hubble–Sandage variable stars, and he went on to classify less-violent pulsations that actually do occur in stars like the Sun (1941).

Cowling's close scientific association with **Ludwig Biermann,** and perhaps other central European colleagues, led to his being considered unreliable during World War II. He remained in his department, although he realized afterward that some of the problems Chapman asked him to work on (gas diffusion theory for instance) had been relevant to the atomic bomb project and others to the development of radar. Back problems from 1957 onward and a mild heart attack in 1960 gradually curtailed Cowling's activities. Although he had been a strong proponent of a national center of theoretical astrophysics, by the time such centers were established in Cambridge and Sussex in the late 1960s, he was not able to relocate.

Recognition of Cowling's work came in the form of a Gold Medal of the Royal Astronomical Society, the Bruce Medal of the

Astronomical Society of the Pacific, election to the Royal Society (London), and award of its Hughes Medal of which he never learned, dying just 2 days after the announcement. He served as president of the Royal Astronomical Society (1965–1967) and of the Commissions of the International Astronomical Union on stellar structure (1955–1958) and on magnetohydrodynamics (a field in which he was a pioneer) and physics of ionized gases (1964–1967). Cowling was both unusually tall and unusually (even for his generation) given to formal dress, so that an unsuspecting younger astronomer might well find himself being introduced in effect to Cowling's middle waistcoat button.

Emmanuel Dormy and *Virginia Trimble*

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Crabtree, William

Born **Broughton near Salford, (Greater Manchester), England, June 1610**
Died **Broughton near Salford, (Greater Manchester), England, July 1644**

William Crabtree was among the first to observe a transit of Venus.

The son of a prosperous yeoman farmer, Crabtree studied at Manchester Grammar School. He received no university education, making a career as a clothier or a merchant in Manchester from 1630 or so. He was also employed as a land surveyor and a cartographer.

Self-educated in astronomy, Crabtree made precise observations by which he could establish the latitude of Manchester. By such observations, he was convinced of the accuracy of the *Rudolphine Tables* published by **Johannes Kepler** in 1627, so Crabtree converted the tables to decimal form and accepted Kepler's theory of elliptical planetary orbits.

Crabtree's correspondence with **Jeremiah Horrocks** and **William Gascoigne** about clocks, telescopes, and micrometers shows his recognition of the importance of instruments in refining observational accuracy. As one of the earliest Englishmen to study sunspots, Crabtree closely collaborated with Horrocks on the observation of the transit of Venus across the Sun. According to Keplerian calculations, this rare event would take place on 4 December 1639. Crabtree and Horrocks set up their instrument in Hoole, near Liverpool, and observed the transit at the right time. Projecting the image of the Sun from their telescope on to a graduated sheet of paper, they could deduce the value of the Sun–Earth distance as 14,700 times the radius of the Earth. This value for the Astronomical Unit was much more accurate than any calculated hitherto. Ford Madox Brown painted the astronomer-merchant observing the Venus transit in one of the twelve historical murals commissioned to decorate the Great Hall of Manchester's new Town Hall in about 1880. Crabtree, who was a wealthy and healthy 29-year-old merchant in 1639, is depicted as a wild-eyed, skeletal septuagenarian observing with a brass telescope of late 18th-century design, and he is accompanied by an appropriately pre-Raphaelite wife!

Jean-Pierre Luminet

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Craig, John

Flourished **Scotland, 1589**

Scot physician John Craig was an Aristotelian apologist in conflict with **Tycho Brahe**. He proposed that the center of planetary motion might be a point *between* the Earth and the Sun.

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Critchfield, Charles Louis

Born **USA, 1910**
Died **Los Alamos, New Mexico, USA, 12 February 1994**

American physicist Charles Critchfield worked out the reaction rates for the proton–proton chain (1938) with **Hans Bethe**.

Selected Reference

Schweber, Silvan S. (1986). "Shelter Island, Pocono, and Oldstone: The Emergence of American Quantum Electrodynamics after World War II." *Osiris* 2: 265–302.

Croll, James

Born **near Wolfhill, (Tayside), Scotland, 2 January 1821**
Died **Perth, Scotland, 15 December 1890**

British geologist James Croll was an early climatologist; he turned to astronomy looking for a cause for "glacial ages." He found one in changes of the Earth's orbital eccentricity.

Croll's cosmogony was the product of a search for a solar-luminosity source lasting "100 million years" of geologic time. Neither a meteoric nor a nebular-contraction hypothesis appeared to provide enough energy. But what if the Sun was formed from material that was already hot? Croll turned to astronomy again: He envisioned the extra heat resulting from the inelastic *collision* of two half-solar-mass bodies.

Autobiographies are rare among astronomers and cosmologists. Fortunately, Croll left us a partially finished one. It was augmented and published as *Autobiographical Sketch of James Croll*.

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Irons, James C. (1896). *Autobiographical Sketch of James Croll*. London: Edward Stanford.

Crommelin, Andrew Claude de la Cherois

Born **Cushendun, Co. Antrim, (Northern Ireland), 6 February 1865**
Died **London, England, 20 September 1939**

Andrew Crommelin is perhaps best remembered for his accurate prediction of the return of comet 1P/Halley in 1910.

Crommelin was born in a family of French extraction in Ireland, a descendent of the founder of the Irish linen industry in Ulster. He was educated at Marlborough College and Trinity College Cambridge, graduating in 1886. For several years, Crommelin served on the staff at Lancing College, during which time he continued to pursue observational astronomy, his avocational interest since childhood. He was elected a fellow of the Royal Astronomical Society [RAS] in 1888.

In 1891, Crommelin joined the staff of Greenwich Observatory as a regular observer with the transit circle, the Airy altazimuth, and the Sheepshanks equatorial telescopes. Over time, he became expert in observing comets; computation of orbits for comets, and for asteroids, became his particular area of expertise.

After noting that the extant predictions of comet Halley's return (by **Anders Ångström** and **Philippe de Pontécoulant**) differed by 3 years, Crommelin asked **Philip Cowell** to join him in an effort to improve that prediction. Together, Crommelin and Cowell developed an improved method of accounting for the perturbations of comet orbits and simplified the necessary tables for prediction. Their predicted date of perihelion passage (16.61 April 1910, published in 1908) differed by only 3.03 days from the actual date, a remarkable improvement over the previous efforts. Furthermore, in connection with this effort, Crommelin and Cowell prepared an improved table of all the previous apparitions of Comet Halley back to the year 240 BCE. For their effort, Crommelin and Cowell each received the Lindemann Prize of the Astronomische Gesellschaft and were awarded D.Sc. degrees (*honoris causa*) by Oxford University.

Crommelin continued to observe as well as to compute orbits, and participated as a private member in a number of solar eclipse expeditions. He was one of the two observers (the other being C. R. Davidson) dispatched by Astronomer Royal **Frank Dyson** to Sobral, Brazil, to observe the total solar eclipse on 29 May 1919, while **Arthur Eddington** led a similar effort at Principe Island. It was on the basis of the photographic plates taken during this eclipse, primarily those from Sobral, that **Albert Einstein**'s prediction of the bending of light in a gravitational field was confirmed for the first time.

For many years, Crommelin served as the director of the British Astronomical Association's [BAA] Comet Section, and it was in this capacity that in 1922 the International Astronomical Union asked Crommelin to supervise the preparation of a sequel to **Johann Galle**'s *Cometenbahnen*. With the assistance of BAA members, the *Comet Catalogue* was published in 1925 and kept up to date with continuations thereafter.

Crommelin was active in the leadership of both the RAS and the BAA, serving on the council of each organization for many years, as president of the BAA (1904–1906) and as secretary (1917–1922) and president (1929–1930) of the RAS.

In 1897, Crommelin married Letitia Noble; they had four children.

Thomas R. Williams

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Melotte, P. J. (1940). "Dr. A. C. D. Crommelin." *Observatory* 63: 11–13.

Crosthwait, Joseph

Born **England, 1681**
Died **England, 1719**

After **John Flamsteed'**s death, his chief assistant at the Royal Observatory, Joseph Crosthwait, and **Abraham Sharp** completed and saw through the publication of Flamsteed's *Historia Coelestis Britannica and Atlas Coelestis*.

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Forbes, Eric G. (1975). *Greenwich Observatory*. Vol. 1. London: Taylor and Francis.

Cuffey, James

Born **Chicago, Illinois, USA, 8 October 1911**
Died **Bloomington, Indiana, USA, 30 May 1999**

James Cuffey, an early specialist in photoelectric photometry, was educated at Northwestern University (graduated: 1934) and Harvard (Ph.D.: 1938), and joined the small astronomy department at Indiana in 1938. From 1941 to 1946, he served in the United States Navy as navigation instructor at the Naval Academy.

Cuffey invented and later patented the Cuffey iris photometer for measuring the density of images on photographic negatives as a measure of the light intensity recorded in the emulsion. A student of color–magnitude relationships in globular and open clusters, he published light curves for cluster variables and was recognized for his photometric atlas of M53. In 1966, Cuffey joined **Clyde Tombaugh** in building up astronomy at New Mexico State University, choosing its observatory site, creating several small meteor observatories, and organizing the program. At both Indiana and New Mexico State, Cuffey was a much respected teacher.

Richard A. Jarrell

Selected Reference

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Cunitz [Cunitia, Cunitiae], Maria

Born **Silesia, (Poland), *circa* 1604–1610**
Died **Pitschen (Byczyna, Poland), 22 or 24 August 1664**

Maria Cunitz was one of the first modern *femmes de science*. Cunitz was the eldest daughter of Maria Schultz and Dr. Heinrich Cunitz, a learned physician. Denied any form of university education, Cunitz first received instruction from her father, and in 1630 married Dr. Elias von Löwen (Elie de Loewen, who died in 1661, a physician at Pitschen in Brieg, Silesia), who shared her interests in astronomy. Known as the "Silesian Pallas," Maria Cunitz did not confine her interests to Urania. By one tradition she mastered seven languages (Hebrew, Greek, Latin, German, Polish, Italian, and French) and was widely known for her skills in painting, music, and poetry, not to mention the "masculine" pursuits of mathematics, medicine, and history. Private correspondence shows her interest in horoscopes and genealogy. The most noted woman astronomer since **Hypatia**, Cunitz's principal interest was astronomy. One tradition praises her for her efforts – she worked all night and slept all day – while another charges that her passion for astronomy distracted her from her domestic duties.

As an astronomer, Cunitz is best remembered for her *Urania propitia* (1650). Shortly after the onset of the Thirty Years' War, Cunitz and her husband took refuge in the village of Lugnitz, near the convent of Olobok (Posen), where she composed her work. Dedicated to Emperor Ferdinand III, the *Urania propitia* contains an important preface by her husband that disclaims his authorship, clearly attributing it to Cunitz. Following an introduction (Latin and German), *Urania proptia* provides astronomical tables based on **Johannes Kepler**'s *Rudolphine Tables*. Surprisingly, Cunitz's sole publication was not widely known, perhaps because few copies were printed. Few copies exist today.

Following the appearance of the *Urania propitia* – and here her efforts are not widely recognized today – Cunitz made repeated efforts to join the Republic of Letters, successfully corresponding with the major astronomers of the day: **Pierre Gassendi**, **Ismaël Boulliau**, **Johannes Hevel**, and other advocates of the New Science, among them Pierre Desnoyers and J-A Portner. (Unpublished letters are found at Paris and Vienna.) The letters are telling. By tradition, such letters were addressed – in the name of propriety – to the woman's husband. But learned communication between the sexes during this period (illustrated below) was in its infancy. Here reigning stereotypes required careful attention to protocol as well as extensive poetic padding, for example, one letter goes on at length about the freshness of the "Spring air" and flowers "adorning the earth with varied and resplendent colors." But between the lines other concerns were at work. In the same letter there is a suggestion of something unnatural about women doing geometry. The concern is expressed in the play of words that nature "sports" with us. What does nature conceal behind those "natural curves" with "masculine minds" – natural jest or monstrous sport?

In the end, the Republic of Letters judged the *Urania propitia* positively. Cunitz was praised for extending Kepler's efforts and simplifying his calculative methods for eclipses and especially planetary latitudes. Simplicity aside, Boulliau judged Cunitz's tables less accurate than his own, particularly for Jupiter, Saturn, Mercury, and the Moon, and indeed, Cunitz's tables are seldom mentioned. A century later, **Alexandre-Guy Pingré** and **J-B Delambre** agreed, the latter concluding that Cunitz's tables did nothing for astronomy but disfigure Kepler in the name of convenience. Always acerbic, Delambre ignored the fact that a number of post-Keplerian tables, the *Urania propitia* included, were more accurate than those of Kepler, at least for several planets. Cunitz published nothing further.

Robert Alan Hatch

Alternate name

Kunicia, Maria

Selected Reference

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Cunradus Dasypodius

➔ **Rauchfuss, Konrad**

Curtis, Heber Doust

Born **Muskegon, Michigan, USA, 27 June 1872**
Died **Ann Arbor, Michigan, USA, 9 January 1942**

A man of many talents – classicist, linguist, and astronomer – Heber Curtis displayed a keen eye for recognizing the most pressing astronomical problems of his era. After being surpassed on several fronts, Curtis shifted from notable observer to capable administrator, where he continued to guide the research of others. His name appears most often now in connection with the 1920 Curtis-Shapley debate on the distance scale of the Universe.

Curtis, elder son of Orson Blair Curtis and Sarah Eliza Doust, moved with his family to Detroit when he was seven. Curtis's father, a Civil War veteran, had been wounded at the Battle of Fredericksburg but survived the amputation of his left arm. Orson Curtis nonetheless completed his education at the University of Michigan and later secured a position with the United States Customs Service in Detroit. Curtis's mother, a native of Maidstone, England, was educated at Albion Female Seminary; she was fond of English literature and music.

Curtis graduated from Detroit High School in 1889, where he displayed not only an aptitude for languages but also proficiency with machine tools. He enrolled at the University of Michigan and completed its classical course in three years, studying Latin, Greek, Hebrew, Assyrian, and Sanskrit. Curtis's A.B. degree was awarded in 1892 with Phi Beta Kappa honors; in the following year, he received his AM degree. He also studied mathematics but never took an astronomy or physics course from the Michigan curriculum. In 1895, Curtis married Mary D. Rapier; the couple subsequently raised four children.

Curtis's career, however, was to undergo a dramatic shift, after he was appointed a professor of Latin and Greek at Napa College near San Francisco, California (1894). He began to use the institution's 8-in. refracting telescope. Two years later, Napa College merged with the University of the Pacific, located near San Jose. Remarkably enough, when a teaching vacancy occurred in mathematics and astronomy at the latter school, Curtis was selected. He sought advice from astronomers at nearby Lick Observatory, who allowed him to spend portions of his summer vacations there as a volunteer assistant. These experiences solidified Curtis's desire to become a professional astronomer. But shunning the required coursework at Berkeley, Curtis returned to the University of Michigan during one summer (1899) and worked with astronomer Asaph Hall, Jr., on the orbit of newly discovered comet C/1898 F1 (Perrine).

Determined to earn a Ph.D., so as not to be considered merely a displaced classics scholar, Curtis accepted a two-year Vanderbilt fellowship at the University of Virginia in Charlottesville (1900–1902). **Ormond Stone**, director of its Leander McCormick Observatory, supervised Curtis's dissertation (on the definitive orbit of comet C/1898 F1). Curtis also demonstrated his command of astronomical equipment while assisting the Lick Observatory total solar-eclipse expedition in 1900. This was the first of eleven such trips of which Curtis was either a member or a leader. After being awarded his degree, he was promptly hired as an assistant astronomer by Lick Observatory director **William Campbell** and spent eighteen productive years at the facility.

Curtis became an active participant in Campbell's program to measure radial velocities of the brighter stars. Along the way, numerous spectroscopic binary stars were discovered, by the duplicity of their spectral lines. Campbell and Curtis published the first catalog of these stars in 1905. Campbell's recognition that radial-velocity data should be collected from the entire sky led to his creation of a southern field station erected on San Cristobal Hill near Santiago, Chile. A 37-in. reflector was taken to the site by **William Wright** and one of the Lick Observatory staff. They were joined by Curtis in 1906, who, along with his wife and children, settled in the Chilean community. Curtis easily learned the native tongue, and at a Pan–American Scientific Congress held in Santiago during 1908/1909, he delivered three papers in Spanish. Curtis might have stayed on indefinitely in Chile, had he not been called back to California in 1909 to fulfill another assignment.

Lick Observatory astronomer **Charles Perrine**, who had continued the photographic study of "nebulae" begun by **James Keeler**, was appointed director of the Cordoba Observatory in Argentina. Curtis became his replacement and took charge of the 36-in. Crossley reflector, with which the most successful photographs had been obtained. "Nebulae" had been differentiated among other classes into the gaseous "planetary" nebulae, and the far more numerous "spiral" or "white" nebulae. Perhaps sensing a less intractable problem, Curtis initially concentrated on the former, comparing their sizes, shapes, and distribution across the sky. While the true nature of these objects and their relationship to stellar evolution remained unknown, Curtis's detailed study, published in 1918, offered the most complete synthesis of the planetaries to date.

The much larger category of "spiral" nebulae soon attracted Curtis's attention and provided one of the foremost scientific experiences of his career. Like others of his day, Curtis initially accepted the notion of "spirals" as revolving clouds of matter that were condensing into stars and planetary systems. But a growing body of evidence, both spectroscopic and photographic, was to change Curtis's mind. As reported by **Vesto Slipher**, a number of "spirals" exhibited large redshifts, implying rapid motions along the line of sight and seeming to contradict their occurrences as members of the Milky Way system. With one notable exception, "spirals" were distributed rather uniformly across the sky; that anomaly being the plane of our galaxy, dubbed the "zone of avoidance."

Curtis's study of the "spirals" revealed them in all possible orientations, ranging from face-on to edge-on. The latter exhibited "dark lanes" of dust and gas, which absorbed light from their interiors, and were strongly reminiscent of other "dark" nebulae recognized within the Milky Way itself. To Curtis, it seemed logical that the "spirals" could only be gigantic stellar systems resembling the Milky Way, but lying at enormous distances. Their numbers, he calculated, exceed some 700,000 objects, to the limits of contemporary photography. If the Milky Way were surrounded by a similar ring of dust, then the "zone of avoidance" of the "spirals" could be readily explained. Further evidence came from the occasional appearances of "bright" novae (now recognized as supernovae) in the "spirals." Curtis began to publish his conclusions in 1917, while employed in wartime duties at San Diego, Berkeley, and Washington. He became the Lick Observatory's spokesman for the "island-universe" theory of "spiral" nebulae – a position that led to his participation in the "Great Debate."

On 26 April 1920, Curtis and Mount Wilson Observatory astronomer **Harlow Shapley** were invited to address the annual meeting of the National Academy of Sciences, in Washington, on the "scale of the universe." Shapley had just found the distances to, and the distribution of, many globular star clusters, which, he argued, swarmed around the Milky Way's center. The principal outcome of Shapley's research was his recognition that our Sun was not located near the galactic center, but instead orbited in the outer regions of the galactic disk. For those who accepted Shapley's conclusions, astronomers' picture of the Milky Way would never again be the same. Shapley, however, remained a skeptic of the "island universe" theory defended by Curtis and continued to believe that "spirals" were merely condensations of matter lying entirely within his "big galaxy" model. Four years later, **Edwin Hubble**'s announcement of a Cepheid variable star within the "Great Nebula" of Andromeda provided definitive support for Curtis's interpretation of the "spirals" as external galaxies.

Curtis's interest in solar eclipses provided another venue along which he advanced to the front lines of astrophysical research. Curtis read a scientific paper published in 1911 by **Albert Einstein**, whose special theory of relativity postulated that light should be deflected at the edge of the Sun by 0.83 arc seconds. (Such a measurement could only be conducted during a total solar eclipse, when the Moon's disk temporarily obscured the Sun itself. Intrigued by this possibility, Curtis published a very credible summary of Einstein's theory. He also convinced Lick Observatory director Campbell to organize an expedition to observe the next available solar eclipse from Russia in August 1914. The eclipse party brought its long-focus cameras to a site near Kyiv, but it was completely clouded out. To make matters worse, World War I broke out while they were in Russia, and the team could not return to the United States through Germany. The Lick Observatory equipment had to be left in the care of Russian astronomers but was not returned until after the war.

Two years later (1916), in his new general theory of relativity, Einstein announced that the deflection of light at the Sun's edge was 1.75 arc seconds, (or double the amount predicted by his special theory. An observational test of this prediction was sorely needed; the next solar eclipse was to be visible from Goldendale, Washington, in June 1918. Curtis and Campbell had to borrow inferior instruments of shorter focal length, but managed to successfully observe the eclipse. Curtis expended every effort to measure and reduce the results from these plates, but because their scale was considerably smaller, he could neither confirm nor deny the predicted effect. Confirmation of the larger deflection of light was instead obtained at a solar eclipse viewed in 1919, whose results were announced in favor of Einstein's general theory by British astronomer **Arthur Eddington**. Only after the Lick Observatory equipment was returned did Campbell and **Robert Trumpler** obtain still more precise observations during a 1922 solar eclipse. By then, however, Curtis's golden opportunity had passed.

During the same year (1920) in which he participated in the "Great Debate," Curtis accepted an appointment as director of the Allegheny Observatory at Pittsburgh. There, he continued the acquisition of stellar parallaxes begun by **Frank Schlesinger**, despite his own lack of experience in this form of investigation. In retrospect, Curtis's move effectively marked the end of his most significant contributions to science, and appears somewhat puzzling. It must be remembered, however, that attainment of an observatory directorship was then regarded as the pinnacle of an astronomer's career. By contrast, the inflexible seniority system at Lick Observatory implied that Curtis could not be appointed as director there until he was almost seventy. The large salary increase that accompanied such a promotion was no small incentive to Curtis, who had four children to put through college, and likely influenced his decision. Health reasons might have curtailed Curtis's career as an observer; in later years, he suffered from a progressive thyroid disease that seemingly impaired his immune system.

In 1930, Curtis returned to his *alma mater* and accepted the directorship of the University of Michigan Observatory. This invitation carried with it an assurance of funding for the construction of a large (98-in.) reflecting telescope. But only one year later, support for this venture was withdrawn by the impact of the Great Depression, and the telescope was never built. Its mirror, cast but not fully figured, eventually became the Isaac Newton Telescope, now in the Canary Islands. Instead, Curtis's energies were largely directed toward development of the McMath–Hulbert Observatory at Lake Angelus, Michigan, where pioneering motion-picture studies of solar phenomena were conducted by **Robert McMath**.

Curtis's department produced a number of Ph.D.s during the 1930s, and he himself was instrumental in hiring astronomer **Leo Goldberg**, who later revived the Michigan program. Curtis's most notable publication from this era was his lengthy review on "The Nebulae," published in the fifth volume of the *Handbuch der Astrophysik* (1933). Treating both galactic nebulae and "spirals," it adopts a transitional viewpoint en route to acceptance of the expanding Universe.

Toward the close of his career, Curtis somewhat reverted to his earlier humanistic interests, and coauthored two works addressing issues on science and religion. Although remaining a theist, Curtis declared himself an agnostic on some of the "great unanswered questions" that "may be forever beyond us." In delivering a keynote address at the dedication ceremony of Philadelphia's Fels Planetarium, for example, Curtis argued that one of astronomy's principal attractions was that, "more than any other science, [it] gives us a glimpse of the infinite."

During his lifetime, Curtis received many honors and distinctions, which included the presidency of the Astronomical Society of the Pacific (1912), vice presidency of the American Astronomical Society (1926), and vice presidency of Section D (Astronomy) of the American Association for the Advancement of Science (1924). He also served on Commission 13 (Solar Eclipses) of the International Astronomical Union.

Over 200 of Curtis's letters are preserved in the Mary Lea Shane Archives of the Lick Observatory, University of California, Santa Cruz. Additional letters are found in the Archives of Industrial Society, University of Pittsburgh, and in the University of Michigan Historical Collections, Bentley Library, Ann Arbor.

Jordan D. Marché, II and *Rudi Paul Lindner*

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Curtiss, Ralph Hamilton

Born **Derby, Connecticut, USA, 8 February 1880**
Died **Ann Arbor, Michigan, USA, 25 December 1929**

American spectroscopist Ralph Curtiss made the pioneering and essentially correct suggestion that the difference between the two spectral sequences of cool stars, types K and M, and types R and N, was that the former had oxidizing atmospheres (more oxygen than carbon) and the latter reducing atmospheres (more carbon than oxygen).

Curtiss was the eldest son of Hamilton Burton and Emily Wheeler Curtiss; the next older of his two brothers became a professor of mathematics after attending the University of California.

Ralph Curtiss started as a physics major but, coming under the influence of **Armin Leuschner**, completed his BS in astronomy in 1901. He continued his graduate work at Lick Observatory, after participating in a solar eclipse expedition to Sumatra in May 1901. At Lick Observatory, Curtiss worked with **William Hussey** and **Robert Aitken**.

Curtiss received his Ph.D. in 1904 for a method for the reduction of the measurements of stellar spectra to determine radial velocities, applying the method to the Cepheid variable W Sagittarii. After 4 years as a Carnegie fellow at Lick Observatory, he spent 2 years, 1905–1907, at Allegheny Observatory working with **Frank Schlesinger**, where he helped to develop a new spectrograph.

Hussey left Lick Observatory to become director of the University of Michigan's Detroit Observatory, and Curtiss was appointed to an assistant professorship of astrophysics there in 1907. Curtiss was promoted to associate professor in 1911 and to full professor in 1918 after teaching navigation during World War I. Curtiss became director of the Detroit Observatory upon the death of Hussey in 1926 and was in the process of developing a more desirable site for the observatory when a heart attack, following pleurisy, took his life.

The new spectrograph for Michigan's 37.5-in. telescope was largely Curtiss's design, and he also developed much of the instrumentation for the Michigan southern site at Bloemfontein, South Africa with which his student, **Richard Rossiter**, discovered a very large number of double stars. Curtiss directed 13 Ph.D. dissertations at Michigan, five of the degrees being earned by women students. Among the men was **Dean McLaughlin** who was in many ways his successor.

Curtiss's own work remained largely focused on the interpretation of stellar spectra. At the time of his death he had nearly completed a chapter on "The Classification and Description of Stellar Spectra" for the *Handbuch der Astrophysik*. His most important conclusion was that the empirical classification of spectral lines was substantially complete, but that there was not yet any rational theory for associating the spectral types with surface temperatures, surface gravities, and atmospheric compositions of the stars. Developing these associations required the early stages of quantum mechanics as well as understanding of ionization and excitation of atoms, physics that was just coming into existence when Curtiss died. The ideal classification scheme, that of **William Morgan** and **Philip Keenan**, was more than a decade away.

Curtiss was active in the International Astronomical Union in its formative years and in the American Astronomical Society (his 3-year term as councilor [1927–1930] being cut short by his death). He was a gifted musician (particularly fond of the violin), a fisherman, and one of the framers of the rules for the Boy Scout merit badge in astronomy.

Dorrit Hoffleit

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Curtz, Albert

Born **Munich, (Germany), 1600**
Died **Munich, (Germany), 19 December 1671**

Albert Curtz was the editor of **Tycho Brahe's** astronomical tables. He was the son of the Bavarian nobleman Philipp Curtz. After studying in the gymnasium in Munich, Curtz entered the Society of Jesus in 1616. He was appointed a teacher of mathematics in Dillingen and was later given the position of *Domprediger* (preacher) in Vienna. In 1646, Curtz was made the rector of the college in Neuburg, and then held the same position at schools in Eichstätt and Lucen. Sometime after again accepting the post as rector Neuburg in 1663, Curtz moved back to his birthplace of Munich.

Curtz wrote on several subjects, including military science and the Old Testament. As an author, he used the pseudonym Lucius Barrettus, an anagram of the Latinized version of his name, Albertus Curtius. Curtz took upon himself the task of editing for publication Brahe's astronomical tables. His edition of the tables was published as *Historia coelestis* in Augsburg in 1666. However, this edition was riddled with typographical errors. **John Wallis** wrote Henry Oldenburg about his disappointment with *Historia coelestis*. "I regret finding many typographical errors, in the printing of the letters at any rate, which makes me suspect that the same had happened with the numbers … in matters of this kind this is important, for they cannot be corrected from the sense." Wallis went on to suggest that "those who had charge" print a list of errata. In addition to the private disappointment of men like Wallis, the *Historia coelestis* was publicly criticized by **Erasmus Bartholin**. In *Specimen recognitionis* (Copenhagen, 1668), Bartholin decried Curtz's editorial work and hinted that he planned on issuing a more correct edition of Brahe's tables.

Derek Jensen

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Cysat, Johann Baptist

Born **Lucerne, Switzerland, *circa* 1586–1588**
Died **Lucerne, Switzerland, 3 March 1657**

Johann Cysat was a pioneer of telescopic astronomy and observed sunspots, comets, and nebulae using telescopes he constructed. Cysat, one of fourteen children of Renward Cysat, an important civic leader in Lucerne, entered the Jesuit order as a novice in 1604. By 1611, he was a student of **Christoph Scheiner** at the Jesuit College of Ingolstadt, where he succeeded Scheiner as professor of mathematics and astronomy from 1616 until 1622. Cysat was Rector of the Jesuit College in Lucerne from 1623 to 1627, after which the order sent him to Spain before he returned to Ingolstadt in 1630. By the following year, Cysat moved to Innsbruck, where he served as the architect of the Jesuit College church, remaining as rector of the Jesuit College there from 1637 to 1641, in Eichstadt from 1646 to 1650, and then in Lucerne until his death.

Although many details of his astronomical work remain uncertain, Cysat did observe sunspots with Scheiner in March 1611 and defended Scheiner's priority of discovery over **Galileo Galilei**. Cysat was possibly the first Swiss to make telescopes, building a 6-ft.- and a 9-ft.-long refractor to observe comets. In *Mathemata astronomica de loco, motu, magnitudine, et causis cometae*, he described his observations, particularly those of the comets, which he believed circle around the Sun. In Cysat's survey of the sky, this pioneer of telescopic astronomy independently observed the Orion Nebula (M42) shortly after its discovery by **Nicolas Peiresc** in 1611. Cysat made an early telescopic observation of the comet C/1618 W1 and observed the lunar eclipse of 1620. While in Innsbruck on 7 November 1631, he may have been one of the few astronomers anywhere to observe the transit of Mercury predicted by **Johannes Kepler**, who had once visited Cysat in Ingolstadt. One letter from Cysat to Kepler (dated 23 February 1621) is known.

The "Monticuli Cysati," mountains at the Moon's south pole, are named in Cysat's honor; in 1935, so was a lunar crater of about 48 km in diameter at 66°.2 S 6°.1 W.

Marvin Bolt

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D

d'Agelet, Joseph

Born **Thonne-la-Long, (Meuse), France, 1751**
Died **1788**

In 1783, French astronomer Joseph d'Agelet was cataloging stars when one (WY Sagittae) disappeared from view. For more than a century d'Agelet's Star perplexed observers. Then, in the 1950s, Lick Observatory astronomers in California located a faint star at the same coordinates. D'Agelet had happened to catch a nova.

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d'Ailly, Pierre

Born **Compiègne, (Oise), France, 1350 or 1351**
Died **Avignon, France, 1420**

Pierre d'Ailly remained an important authority for cosmographers and astrologers throughout the Renaissance period.

D'Ailly was born in Compiègne to prosperous burghers Colard d'Ailly and his wife Pétronille. D'Ailly studied at the University of Paris, where he received the licentiate in arts in 1367 and became a doctor of theology on 11 April 1381. D'Ailly had a distinguished career in both university and church, serving as rector of the College of Navarre of the University of Paris from 1384, chancellor of the University of Paris from 1389 to 1395, Bishop of Le Puy from 1395 to 1396, Bishop of Noyon from 1396 to 1397, Bishop of Cambrai from 1397, and Cardinal from 1411 until his death in Avignon in 1420. One of the most prominent churchmen during the years of the Great Schism (1378–1414), d'Ailly was also a prolific author in the areas of theology, ecclesiology, and natural philosophy, including astrology.

D'Ailly's interest in the stars dates back to his days in Paris, although his early writings reveal no great expertise in or love of astrology. Two treatises with basic astronomical material, the *Tractatus super libros metheororum de impressionibus aeris* (a commentary on **Aristotle**'s *Meteorology*, including sections on comets) and the *Questiones* on **John of Holywood**'s *Sphera* (a commentary on a basic astronomical textbook), most likely date from his years of lecturing in the faculty of arts (1368–1374). D'Ailly's early hostility to astrological predictions emerges in other treatises written in Paris before 1395, such as the *De falsis prophetis, II* (On false prophets, II) and the *Tractatus utilis super Boecii de consolatione philosophie* (a commentary on **Boethius**'s *Consolation of Philosophy*). Despite these early condemnations, d'Ailly wholeheartedly embraced the "science of the stars" in the years after 1410.

In the final decade of his life, inspired by a reading of the Franciscan **Roger Bacon**, d'Ailly composed an important series of cosmological and astrological treatises, including *Imago mundi* (Image of the world, 1410), *De legibus et sectis contra superstitiosos astronomos* (On the laws and the sects, against the superstitious astrologers, 1410), *Vigintiloquium de concordantia astronomie cum theologia* (Twenty sayings on the concordance of astrology and theology, 1414), and *Concordantia astronomie cum hystorica narratione* (Concordance of astrology with the narration of history, 1414). In these treatises, d'Ailly defended astrology's use in predicting large-scale change, including mutations in religions, and demonstrated particular expertise in the astrological doctrine of the great conjunctions. The latter teaching represented a means of making long-term predictions based largely on the pattern formed by successive mean conjunctions of Saturn and Jupiter. Those conjunctions falling every 240 years (great conjunctions) and 960 years (greatest conjunctions) were said to have particular significance for human affairs. D'Ailly also explored the vexing problem of calendrical reform in treatises such as *Exhortatio super Kalendarii correctione* (Exhortation to the correction of the calendar, 1411; presented to Pope John XXIII and also read before the Council of Constance) and *De vero cyclo lunari* (probably from the same time). The culmination of d'Ailly's astrological studies, revealed in the *Concordantia astronomie cum hystorica narratione* and again in the treatise *De persecutionibus ecclesie* (On the persecutions of the church), completed in 1418, was his prediction of the appearance of the Antichrist in or around the year 1789. Only a century earlier, scholars had denied that such an astrological prediction of the apocalypse was possible or licit. D'Ailly's prognostication for 1789 rested on the convergence of three astrological signifiers: a greatest conjunction of Saturn and Jupiter, the completion of ten revolutions by the planet Saturn, and an alteration in the position attained by the *accessus* and *recessus* of the eighth sphere. (The latter phrase refers to one of the explanations of the precession of the equinoxes offered in the Alfonsine Tables.) First proposed on the eve of the Council of Constance that would finally end decades of schism, d'Ailly's prediction for 1789 offered reassuring hope that the division in the church did not, in fact, signal the imminent end of the world, as many had feared.

A number of d'Ailly's astrological treatises appear in two important incunable editions (Louvain 1483 and Augsburg 1490) as well as in numerous manuscript copies. His commentary on Sacrobosco's *Sphere* also was printed a number of times in the 15th and 16th centuries. The noted astrologer **Johann Müller** (Regiomontanus) knew and praised his work on conjunctions. Christopher Columbus owned and annotated d'Ailly's *Imago mundi* and other astrological works, and d'Ailly's astrological predictions helped confirm Columbus's own sense of apocalyptic mission. D'Ailly's prognostication for 1789, and in particular his use of the period of *accessus* and *recessus* of the eighth sphere, formed a model for such later astrologers as Jean de Bruges in the 1440s and Pierre Turrell in the 1530s. Similarly, Müller praised his work on conjunctions. Through his prestige as scholar and cardinal and through his example of an astrological forecast of the end of the world, d'Ailly may be said to stand at the head of the flood of such astrological apocalyptic prognostications that engulfed Europe in the late 15th through 17th centuries.

Laura Ackerman Smoller

Alternate names

Petrus de Alliaco
Peter of Ailli

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d'Alembert [Dalembert], Jean-Le-Rond

Born **Paris, France, 16 November 1717**
Died **Paris, France, 29 October 1783**

The works of Jean Le Rond d'Alembert in astronomy focused on celestial mechanics, then called "physical astronomy." His greatest works were his theoretical explanation of the observed phenomena of precession and nutation and his lunar theory. The mathematical operator called the d'Alembertian is used today in special relativity among other applications. The illegitimate son of Madame de Tencin and the Chevalier Louis-Camus Destouches, he was abandoned by his mother in front of a small church in Paris called Saint-Jean-Le-Rond, whose name was given to him by the authorities. Soon after, his father had him put in the care of a glazier's wife to whom Jean always remained attached. Thanks to Destouches and his family, Jean Le Rond received a good education and entered a famous school, the Collège des quatre nations, where he was initiated into mathematics. At that time, he began to be called d'Alembert, probably on the initiative of the Destouches family.

After early works on pure mathematics and mechanics, d'Alembert entered the Paris Royal Academy of Sciences in 1741 and wrote several memoirs and treatises in the same disciplines, in particular the first edition of his *Traité de dynamique* in 1743. His astronomical production began in 1746, when he sent a memoir titled *Solution de quelques problèmes d'astronomie* (published in 1749) to the Berlin Academy, to which he was recently elected a foreign member. More astronomical memoirs were sent to Berlin during 1747; they concerned the motion of the Moon and planets, but were withdrawn from publication by d'Alembert.

In June 1747, d'Alembert read two memoirs on celestial mechanics to the Paris Academy. The first one, *Méthode générale pour déterminer les orbites et les mouvemens de toutes les planètes, en ayant égard à leur action mutuelle* (published in 1749), contains the basic principles of his lunar theories and his method for determining the apsidal motion. The second one (manuscript in the Bibliothèque nationale, published in 2002), which presents the results of an early theory for the Moon's motion and perturbations of the Earth's motion by the Moon, was withdrawn from publication. Toward the end of 1747 and the beginning of 1748, d'Alembert concentrated on lunar theory. Partial results were quoted in several *Plis cachetés* deposited at the Paris Academy of Sciences – two of them still exist at the archives of the academy – and in the memoir *Application de ma méthode pour déterminer les orbites des planètes à la recherche de l'orbite de la Lune* (published in 1749); his second lunar theory was finished in August 1748 (manuscript in the Bibliothèque nationale, published in 2002 under the title *Théorie de la Lune de 1748*). But like **Alexis Clairaut**'s and **Leonhard Euler**'s calculations, d'Alembert's theoretical calculations yielded only the half value of the mean motion of the lunar apsides. On 15 November 1747, Clairaut read a memoir to the academy, attributing this discrepancy to the Newtonian law of gravitation and suggesting that the inverse-square term be completed by another term. D'Alembert did not take part in the controversy raised by Clairaut's communication, but he discussed the problem in his correspondence with Euler, and both tried unsuccessfully to explain the discrepancy by perturbations due to the shape of the Moon. Finally, one of the conclusions of the 1748 lunar theory is that the Newtonian law must not be changed, but that another force (a magnetic force perhaps) acts in the vicinity of the Earth.

During the last months of 1748 and the first months of 1749, d'Alembert worked on theories of the precession of equinoxes and nutation. **James Bradley** had announced his discovery of nutation in the 1748 volume of *Philosophical Transactions*, but it had been known for several years. D'Alembert succeeded in completely explaining the observed phenomena within the frame of the Newtonian law, by using the third principle of his *Traité de dynamique*. His new treatise, *Recherches sur la précession des équinoxes et sur la nutation de l'axe de la Terre dans le systême newtonien*, appeared in July 1749. It also contains a critical analysis of the precession theory in **Isaac Newton**'s *Principia* and a determination (close to the modern value) of the ratio of the Moon's mass to the Earth's.

Meanwhile, Clairaut had found the origin of the discrepancy concerning lunar apsides: an insufficient precision in the resolution of the differential equations. In fact, Euler, Clairaut, and d'Alembert had obtained the developed expression of the apsidal motion up to the order two only, with respect to the ratio of Moon's and Earth's periods, while the contribution of the third-order term is almost as large. Nevertheless, d'Alembert's 1748 lunar theory presents a theoretical interest in the calculation of periodic inequalities and stands for the first literal theory of the lunar motion.

D'Alembert went back to lunar theory in December 1749. At the end of February of the following year he had a correct value of the apsidal mean motion, and his new theory was finished in January 1751. But a dispute with Euler dissuaded him from submitting his manuscript to the Petersburg Academy for the 1752 prize, which was won by Clairaut. This third lunar theory of d'Alembert was close to his 1748 theory; the primary difference consists in the expression of the apsidal mean motion, now developed up to the order five. It was published in January 1754 as the first book of *Recherches sur différens points importans du système du monde*.

Completed by a third part published in 1756, the treatise on mechanics of celestial bodies contains six books. Books II and V are devoted to planetary motion. Some remarks in Book V about **Nicolas de La Caille**'s observations of the Sun gave rise to a controversy between the two academicians, illustrated by a memoir read by d'Alembert to the academy in 1758 (published in 1762). The first chapter of Book III is a continuation of the 1749 treatise on precession and nutation. It was completed by the memoir *Recherches sur la précession des équinoxes et sur la nutation de l'axe de la Terre dans l'hypothèse de la dissimilitude des méridiens*, read to the academy at the end of 1756 (published in 1759). The second chapter of Book III and Book VI deal with the Earth's figure.

Two sets of lunar tables have been constructed by d'Alembert from his third theory. The first one is inserted in Book I of the 1754–1756 treatise. The second one, *Nova tabularum lunarium emendatio*, was published separately in January 1756 under the form of corrections to late tables of **John Flamsteed** inserted in **Pierre le Monnier**'s *Institutions astronomiques*, but its construction is described in Book IV. Lunar tables gave rise to a controversy between d'Alembert and Clairaut; the subjects were methods of construction, the form of the 1756 tables, and doubts expressed by d'Alembert about the accuracy of **Tobias Mayer**'s tables. It ended by an insertion from d'Alembert in the second edition (1758) of his *Traité de dynamique*.

The subsequent works of d'Alembert in celestial mechanics were, for the most part, published in the eight tomes of his *Opuscules mathématiques*, which appeared between 1761 and 1780. They can be divided into several groups.

Memoirs about comets belong to Tomes II (1761), V (1768), VI (1773), and VIII (1780). The memoirs in Tome II are related to the 1759 return of Halley's comet (IP/Halley). The first one gives a method to determine the perturbations of comet orbits by planets, following two *plis cachetés* deposited by d'Alembert in 1759 (manuscripts at the archives of the Paris Academy of Sciences), but no numerical application is performed. The second one is a mere contribution to the polemic about Clairaut's and Lalande's calculations. In 1762, this polemic gave rise to a hard confrontation between Clairaut and d'Alembert about the whole three-body problem, illustrated by several papers in journals.

Tome II also contains d'Alembert's third lunar tables, in which the arguments of inequalities were provided by theory, and the coefficients were evaluated by comparing several lunar tables. Lalande was very critical about these tables in his *Bibliographie astronomique*.

Several memoirs, in Tomes II, IV (1768), V, and VI of the *Opuscules*, are theoretical studies about the motions of the Moon and planets. Some of them can be connected to the problem of the observed secular acceleration of the Moon and to prizes proposed by the Paris Academy of Sciences between 1760 and 1774, before the provisional solution by **Pierre de Laplace** in 1787. In this context, d'Alembert introduced, in Tome VI, the 200-year inequality now called Laplace inequality. Memoirs about precession, nutation, and the similar problem of lunar libration exist in Tomes II, V, and VI. They were completed by a memoir in two parts, *Recherches sur les mouvemens de l'axe d'une planète quelconque dans l'hypothèse de la dissimilitude des méridiens*, read in 1769 to the academy (published in 1770).

In parallel, d'Alembert was a mathematician and a philosopher, and he wrote a large number of contributions to the masterpiece of the Enlightenment, the *Encyclopédie*, of which he has been an editor along with Diderot.

Michelle Chapront-Touzé

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d'Arrest, Heinrich Louis [Ludwig]

Born **Berlin, (Germany), 13 August 1822**
Died **Copenhagen, Denmark, 14 June 1875**

In addition to discovering three comets and 342 NGC objects, Heinrich d'Arrest assisted **Johann Galle** in discovering Neptune on 23 September 1846. D'Arrest studied mathematics and astronomy from 1839 at Berlin University. He was appointed second assistant observer at the Berlin Observatory in 1845; he left in 1848 to become an observer at the Leipzig Observatory. After earning his Ph.D. in 1850 at the University of Leipzig, he served there as extraordinary professor from 1852. In 1857, d'Arrest married Auguste Emilie Möbius, daughter of mathematician A. F. Möbius, under whom he worked at the observatory. That year, d'Arrest went to Copenhagen as professor of astronomy and director of the observatory there.

In 1845, **Johann Encke**, director of the Berlin Observatory, granted permission to search for the trans-Uranian planet whose location was predicted by **Urbain Le Verrier** that summer (and also independently by **John Adams**). D'Arrest, still a graduate student, suggested to Galle that they make use of one of the unpublished *Berliner Akademische Sternkarten* produced by **Carl Bremiker**. On the first night of searching, 23 September, Galle found an uncharted object, which became known first as Leverrier but soon as Neptune.

D'Arrest discovered comets C/1844 Y2, 6P/1851 M1, and C/1857 D1, all of which now bear his name; comet 6P/d'Arrrest is a short-period comet that has been seen dated to 1678. He also studied properties of minor planets and discovered asteroid (76) Freia.

D'Arrest performed systematic observations of nebulae. In 1857, he published precise coordinates and descriptions of 269 such objects; in 1867, he published his observations of 1,942 nebulae. In 1873, d'Arrest, among the first to observe the spectra of nebulae, demonstrated that nebulae with bright emission lines (gaseous nebulae) lie mostly near the Milky Way.

D'Arrest was a corresponding member of the Saint Petersburg Academy and an associate of the Royal Astronomical Society of London, the Gold Medal of which he received in 1875. In addition to the three comets, his name has also been given to a lunar crater, a crater on the Martian satellite Phobos, and asteroid (13).

Mihkel Joeveer

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d'Aurillac, Gerbert

Born **Aurillac, (Cantal), France, *circa* 945**
Died **Rome, (Italy), 12 May 1003**

Gerbert was a man ahead of his time. Europe did not see as great a contribution to science again for several hundred years.

Gerbert was born sometime between 940 and 950 in or near Aurillac, France, to what has often been described politely as "humble parents" or *une famille obscure et pauvre*. His rise to power was extraordinary in an age when royal blood meant nearly everything in terms of professional advancement. It is a credit to Gerbert's tremendous intellect, which was, unfortunately at the time, often equated with magic and the devil. The exact year of his birth is unknown, though some give 945. What is certain is that he apprenticed to the Church early, beginning his training at the monastery in Aurillac. In 967, Gerbert was taken to Spain by Boreal, count of Barcelona, to study under the Arabian teachers possibly at Cordova and Seville. In 971, Boreal and Octo (Hatto), Bishop of Vich, took Gerbert with them on a mission to Rome, where he attracted the attention of Pope John XIII and Emperor Otto I. The latter employed Gerbert as an instructor to Prince Otto II. In 972, Gerbert was sent back to his native France by Otto I with Archdeacon Garamnus, who taught Gerbert logic. He was to teach at the cathedral school in Rheims for Archbishop Adalbero. Very soon Gerbert was composing Adalbero's letters for him. His fame as a scholar and preeminent teacher was quickly secured and Gerbert's school at Rheims gained the attention of a certain Otric, a master at Magdeburg, who debated Gerbert in 980 at Ravenna, a debate presided over by Otto II. The text of the debate survives to this day, and it is clear that Gerbert gained the upper hand. Otto II was so pleased at the result that he appointed Gerbert in 983 as Abbot of Bobbio, which reportedly was famous not just for scholarship but also for its esteemed library. But his stay was short-lived. Otto II died on 7 December 983, leaving Gerbert, who had ruffled feathers in his year at Bobbio, to flee to France where he again took up a post at Rheims. In 991 he was temporarily elevated to Archbishop of Rheims, a post held by his long-time friend Adalbero who died on 23 January 989. Gerbert was relieved of his duties on 1 July 995. He returned to Italy and Otto III where, in 998, Pope Gregory V appointed him Archbishop of Ravenna. On the death of Gregory V, Gerbert was elected to the papacy on 18 February 999 and adopted the name Sylvester. His reign as pope was filled with church and political duties, and it is not clear whether he made any significant scientific advances during his reign. He died soon after his confidant Otto's death.

There are some who would argue that Gerbert's greatest contribution to astronomy was his teaching. This may indeed be true, for extant writings of both Gerbert and his contemporary Pierre Richer describe in detail his teaching style. Gerbert reportedly used what are now commonly called "visual aids" in his teaching. Richer reports that all of Gerbert's aids were self-constructed, as they would have to have been in the 10th century. Utilizing Richer's and Gerbert's writings, O. Darlington has pieced together a description of some of Gerbert's techniques. His instructions assumed that the world was round and utilized a great amount of knowledge inherited from the Greeks. The latter fact is probably due to his Moorish training, as the Arabic teachers were the keepers of Greek knowledge for the majority of the Middle Ages. Gerbert was also a champion of the spherical Earth concept, which had been believed by many learned Greeks and Arabs, but not often by Europeans. Richer relates how Gerbert would use a wooden sphere of the world, slanting it by two poles on the horizon in order to show the relation of the constellations to the poles (presumably also utilizing a star chart for reference). He apparently drew a horizon line on the sphere in order to demonstrate the rising and setting of the stars and to better demonstrate the reality of observation. Richer also notes that Gerbert proved that the rising and setting of stars was a movement in an oblique direction that covered the various areas of the world. Gerbert reportedly divided his spheres into 60° rather than 360°; his lateral lines were thus equal to six modern degrees. Gerbert's polar circle, then, appeared at 26°, which is off from the actual mark of just over 23°. However, his location of the tropics was nearly exact, and his Equator was exact. This is likely due to the fact that the Earth is not spherical but oblate, which would mean an increase in error with an increase in latitudinal line. Gerbert also used spheres to describe the paths of the planets and constructed what could be considered an early version of a three-dimensional planisphere.

Gerbert made numerous other advances, including that for which he is best remembered: The introduction of Arabic numerals to Europe (an early version of the numerals we use today). He initiated methods of Arabic mathematics into his teaching and thus into Europe itself, and modified the Roman abacus in order to utilize a decimal point. The stones he used on the abacus were called *calculi*. His revision meant that complex mathematics like multiplication and division were no longer solely the domain of specialists.

Ian T. Durham

Alternate name

Pope Sylvester II

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d'Azambuja, Lucien

Born **Paris, France, 21 January 1884**
Died **Salies de Béarn, Pyrénées-Atlantiques, France, 18 July 1970**

French solar astronomer Lucien d'Azambuja inaugurated an 80-year-long sequence of daily images of the solar surface and chromosphere that is a unique data resource for studies of changes in the Sun and their correlations with other phenomena. At the age of only 15, he began working as an assistant at the Observatory of Meudon, near Paris, under **Henri Deslandres**, earning a doctoral degree there many years later, in 1930, for his work on the structure of the chromosphere. In 1908, d'Azambuja was promoted to "astronomer," and he built a large spectroheliograph, which had been designed by Deslandres to study chromospheric structures. The instrument allowed convenient imaging and radial velocity measurements of the different layers in the solar chromosphere. It is especially useful for the study of the solar prominences. Solar prominences – bright clouds on the Sun's limb – were eventually proved to be identical to the dark filaments that can be seen on the Sun's disk with the spectroheliograph each day.

After 1913, when Deslandres and d'Azambuja were convinced that filaments are one of the most important elements of the upper layer of the chromosphere, they proposed a graphic representation that would allow convenient study of individual filaments and of filaments' global distribution. This was the first draft of a synoptic

map for following the chromospheric structures during each 27-day solar rotation. Determining the velocity of rotation and the height of filaments was one of d'Azambuja's scientific passions.

In 1927, the observatories of Paris and Meudon were unified, and Deslandres became the director, leaving the responsibility of the solar department on d'Azambuja. The principal program of the department became the daily survey of the Sun using the spectroheliograph, starting in 1919 and continuing until the present. Every day, three spectroheliograms are obtained in the red line of hydrogen at 6,563 Å; in the continuum at 6,548 Å; and in the blue line of Ca II, K at 3,933 Å. These images are used to make the synoptic charts. More than 100,000 spectroheliograms are collected at the Meudon Observatory. They provide a unique data resource for retrospective solar research and are a tribute to d'Azambuja's dedication.

Research at Meudon was suspended during World War II, but afterward, d'Azambuja and his wife Marguerite Roumens, who had originally been his assistant at the observatory, continued their research, making the first measurement of the rotation of the Sun from the positions of long-lived filaments, rather than from sunspots. Their work, "A Comprehensive Study of Solar Prominences and Their Evolution from Spectroheliograms Obtained at the Observatory and from Synoptic Maps of the Chromosphere Published at the Observatory" (*Ann. de l'Observatoire de Meudon*, Vol. 6, part 7) was published in 1948. This work was a standard reference work in solar physics for many years.

D'Azambuja worked at Meudon until 1959. He published more than 80 papers. His remarkable 60-year career bridged the period from the classical work of **Jules Janssen** and Deslandres to the birth of solar radio astronomy and the space age.

D'Azambuja was president of the Commission on Solar Physics of the International Astronomical Union from 1932 to 1958 and of the Astronomical Society of France (1949–1951). He also presided over a joint commission of the International Council of Scientific Unions established to study solar–terrestrial relations in the 1940s, and was elected to the French Legion of Honor, among other awards.

M. J. Martres and *David M. Rust*

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Daly, Reginald Aldworth

Born **Napanee, Ontario, Canada, 18 March 1871**
Died **Cambridge, Massachusetts, USA, 19 September 1957**

In 1948, Canadian geologist Reginald Daly proposed that the Moon was formed by a collision between the Earth and a planetary-mass body. By 1984, "giant impact" had become the leading theory for lunar origin.

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Damoiseau, Marie-Charles-Théodore de

Born **Jussan Mouthier, (Doubs), France, 9 April 1768**
Died **Issy near Paris, France, 6 August 1846**

Marie-Charles-Théodore de Damoiseau is mostly known for his lunar tables and his tables of the Galilean satellites of Jupiter. He was the son of Louis Armand Désiré de Damoiseau, Chevalier, Seigneur de Colombier, an important military figure, and Jeanne Marie Marmillon de la Baronnie de Montfort. This was Damoiseau's father's second marriage, and he was one of four children. Damoiseau signed as Damoiseau de Monfort (not Montfort), although on his publications, he signed as Baron de Damoiseau.

Clever in mathematics, Damoiseau began his career as an artillery officer in La Fère, but during the French Revolution he became an *émigré* (1792), joining the Condé army on the German border. In 1795, Damoiseau was in the service of the King of Sardinia in the Piedmont region of Italy. With the arrival of the French troops he went to Portugal, to join the marine artillery. Soon he was in charge of nautical ephemerides at Lisbon Observatory, and he began to publish them from 1798. Damoiseau was reinstated in the French army by general Junot who was in Lisbon with his troops in 1807. He was posted to the artillery in Bastia, in Antibes, and, by the end, in the Commission d'artillerie in Paris. When he retired in 1817, as a lieutenant-colonel, Damoiseau began a purely astronomical career.

For his work in astronomy, Damoiseau was granted the Prix des sciences in 1820 by the Académie des sciences. In 1823, he was a candidate for a vacant position as *adjoint* at the Bureau des longitudes, but did not receive it. Damoiseau published his lunar tables in the following year (and another version in 1828), winning the Médaille Lalande, from the prize created by **Joseph-Jérôme de Lalande** a short time before his death. Soon after this, the bureau appointed Damoiseau to act as secretary-librarian for the Paris Observatory. Although no vacant post existed at the Bureau, King Louis XVIII intervened personally, appointing Damoiseau as *membre adjoint* of the Bureau *pour l'application spéciale du calcul numérique aux recherches qui peuvent intéresser l'astronomie, la géographie et la navigation*. It seems likely due to Damoiseau's father's prominence.

Damoiseau became a member of the Académie des sciences in 1825. On the death of **Jean Burckhardt** in that year, Damoiseau took over as director of the École Militaire Observatory. From 1833, he could no longer observe due to his poor eyesight. For some years, the École Militaire wanted to use the observatory buildings for other purposes and did so in 1835. It was probably about this time that Damoiseau moved to Issy, where his widow remained until 1863. (They had no children.) When **Alexis Bouvard** died in 1843, Damoiseau, who had published important astronomical memoirs, replaced him as a full member of the Bureau des longitudes.

In 1836, Damoiseau published his Galilean satellite tables, to replace those of **Jean Delambre**. Damoiseau's tables were used for the *Connaissance des temps* from 1841 to 1914. Apart from his works about the Moon and the Galilean satellites of Jupiter, Damoiseau had also studied on the trajectories of comets and their perturbations and, especially from 1820, the perihelion for the 1835 return of comet Halley (IP/Halley).

Jacques Lévy

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Danjon, André-Louis

Born **Caen, Calvados, France, 6 April 1890**
Died **Paris, France, 21 April 1967**

André Danjon led the recovery of French astronomy to excellence after many decades of neglect and the two world wars fought on French soil. Danjon is remembered for his development of instruments and for his fundamental studies of the Earth's rotation. As a result of his efforts to stabilize and expand the International Astronomical Union [IAU] during the troubled period after World War II, Danjon exercised substantial influence on 20th-century astronomy.

The son of Louis Dominique Danjon and Marie Justine Binet, both drapers, Danjon was one of three siblings. His father was at first an accountant, which may perhaps explain Danjon's lifelong interest in precision and exactness, characteristics he first evinced while a student at the Lycée Malherbe in Caen. In 1910, Danjon was accepted for admission to several of the major French institutions of which he chose the École Normale Supérieure [ENS]. During his studies at ENS, Danjon spent many hours at the eyepiece of the refractor at the amateur observatory of the Société Astronomique de France. He graduated as *agrégé de sciences physiques* in 1914.

When World War I broke out immediately after his graduation from the ENS, Danjon was mobilized and assigned to the sound-ranging service then under the command of astronomer **Ernest Esclangon**. Danjon lost one eye in combat in the Champagne region but remained in active service, receiving the *Croix de Guerre avec Palmes* and *Chevalier de la Légion d'honneur* in 1915.

After the war, in 1919 Danjon accepted a government appointment as *aide-astronome* to a group of high-level teachers sent to the university in Strasbourg, located in the historically contested region of Alsace-Lorraine, which had been ceded to France by Germany as part of the Versailles Treaty. Danjon took up duties as an observer in the Strasbourg meridian service but soon realized the inadequacy of both the century-old equipment and the procedures. His efforts to upgrade the Strasbourg meridian service, and similar later efforts at Paris Observatory, stimulated Danjon's creative instincts for instrumental development.

In 1923, Danjon assumed the additional responsibility of conceptualizing a new observatory for astrophysics, the Observatoire de Haute-Provence in southeast France, which opened in 1936.

In parallel with these activities, Danjon continued to pursue physical observations of celestial objects. Using his invention, the *photomètre à œil de chat* (the cat's eye photometer), Danjon made studies of the earthshine reflected by the dark side of the Moon. His studies were extended to include the albedo of Venus and Mercury as a function of their phase. This work formed the basis for his doctoral dissertation, entitled *Recherches de photométrie astronomique*, accepted in 1928 at Paris University. Danjon was then appointed adjoint astronomer at Strasbourg.

In 1930, Danjon succeeded Esclangon as director of the Strasbourg Observatory when the latter became director of the Paris Observatory. Soon thereafter, Danjon became a full professor, and in 1935, he was appointed dean of the Strasbourg faculty of sciences.

In 1939, German aggression forced the relocation of the entire university faculty including Danjon to Clermont-Ferrand near Vichy, France. Acting as the university rector, Danjon opposed the military use of the university campus, which resulted in his being arrested and jailed in late November 1943. Many of the professors and students arrested in this sweep were sent to Auschwitz, though Danjon and other docents of the university escaped that fate. Released in the following January, Danjon did not recover his position at the university until November 1944. When Esclangon retired in 1945, Danjon replaced him as the director of the Paris Observatory.

On his arrival in Paris, Danjon was faced with the urgent need to restore French observatories. More importantly, Danjon's task should be viewed as restoration of French astronomy, which like many other sciences had been deeply diminished by two successive wars on French territory. As a teacher in La Sorbonne, Danjon had a deep influence over his students due to his very clear presentations and a fondness for astronomy that he demonstrated in his courses. When **Henri Mineur** died in 1954, Danjon assumed the directorship of the Astrophysical Institute of Paris in addition to the Paris Observatory. Danjon occupied many other administrative positions, always showing a great realism as an administrator. Among them are: president of the International Committee on Weights and Measures (1954) and founding president of the French Association for Numerical Computation (1957). He was also a member of the Bureau of Longitudes and was elected to the French Academy of Sciences in 1948.

Danjon's instrumental research focused on astronomical applications of double-image or Wollaston prisms. By 1952, he developed the prototype of a prismatic astrolabe equipped with an impersonal micrometer (now commonly referred to as the *astrolabe de Danjon*). In parallel to photographic zenith tubes, a total of 45 of Danjon's astrolabes were in service for time and latitude determinations at various locations until 1987. On a good night, the Danjon instrument was capable of determining time with an accuracy of 4 ms and latitude to 50 milliarcseconds.

While director in Paris, and still observing in the mid 50s, Danjon established or improved several domains of French astronomical research, expanding coverage to a majority of fields in modern astronomical activities. In 1956, his efforts led to the establishment of the Radio Astronomy Station at Nançay, situated far away from industrial and human-made noise, in Sologne, the Cher department. When his European colleagues suggested establishing a new European observatory in the Southern Hemisphere, as **Adrian Blaauw** later noted, it was Danjon who persuaded the French government to take part in the project, leading to the development of European Southern Observatory stations at La Silla and at Paranal.

For a physicist in the service of astronomy with many administrative duties, the volume of Danjon's publication deserves mention. He published many fundamental papers, for example, on the influence of the Earth's atmosphere on the variations of its rotation; his early works on the reflecting power of the Earth were reconsidered favorably in 1980, remarkable in view of the half a century that had passed. The Danjon scale is used to this day to rate the brightness of lunar eclipses.

A talented popularizer, Danjon's public lectures and his papers in *l'Astronomie*, the magazine of the Société Astronomique de France, now constitute useful sources for those who want to study the evolution of astronomical research during the decades for which he had major responsibilities. An amateur astronomer in his youth, Danjon remained very active within the Société Astronomique de France, encouraging cooperation between its amateur members and professional astronomers. He considered popularization of astronomy a duty for researchers.

Danjon was a corresponding member of astronomical societies in Belgium, Portugal, the United States, Italy, and Great Britain and served as the IAU president from 1956 to 1958. The Royal Astronomical Society [RAS] of London awarded Danjon its highest honor, the RAS Gold Medal, in 1958; that same year he served as the RAS Darwin Lecturer. In 1954, Danjon was *Commandeur de la Légion d'honneur* after being *Officier* in 1946. During the second half of the 20th century, progress in French astronomical science owed a great deal to Danjon.

In 1919, Danjon married Madeleine Renoult, and they had four children; she died in 1965.

Suzanne Débarbat

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Danti, Egnatio

Born **Perugia, (Italy), April 1536**
Died **Alatri, (Lazio, Italy), 19 October 1586**

Egnatio Danti was a master of observational instruments for astronomy and served on Pope Gregory XIII's commission to reform the calendar.

The Rainaldi family had already become quite renowned in the field of humanities and mathematics when Carlo Pellegrino was born. Carlo's grandfather, Pier Vincenzo, was a well-known man of letters and an expert in mechanics, and because of his cleverness his peers nicknamed him Dante or Danti. Pier Vincenzo's brother Giovanni Battista thus decided to adopt the surname of Danti. Carlo Pellegrino received his early education from his father Giulio, who was particularly knowledgeable about instrumental techniques, and from his aunt Teodora, who had a reputation as a painter and scholar of astronomy, mathematics, and geometry.

At the age of 13, Danti entered the Dominican Order and changed his name to Egnatio. Several years later, fame of his knowledge reached the Medici court, where his brother Vincenzo was already working as a sculptor. Thus, in 1562 Cosimo I called him to Florence to paint maps of all the regions in the known world, based on **Ptolemy**'s description, in the wardrobes of the room known as the *Guardaroba* in the Palazzo Vecchio. Cosimo's admiration for his cosmographer grew so much that in 1571 he asked the Dominican Order to allow Danti to live at the Medici palace.

Thanks to Cosimo's benevolence, Danti obtained the mathematics chair at the University of Florence. Here, he began to study the inaccuracies of the Julian calendar then in use. To measure the exact duration of the year, Danti built an astronomical quadrant on the façade of the church of Santa Maria Novella with eight solar clocks and an equinoctial ring that we can still see today. Danti was thus able to observe the spring equinox in 1574, discovering that, in that year, it fell on 11 March of the Julian calendar. For the same purpose, in 1575 Danti started to construct a meridian line in the Santa Maria Novella, but he never completed it due to the death of Cosimo I. With Cosimo's demise, he lost the protection he had enjoyed at the Medici court, and Cosimo's son, Francesco I, banished Danti from Florence.

Consequently, Danti moved to Bologna, where in 1576 he was awarded the chair *ad Mathematicam* that had replaced the chair of astronomy. This position entailed teaching Euclid's *Elements*, **John of Holywood**'s *De Sphaera*, and Ptolemy's *Almagest* and *Theorica Planetarum*. Danti, who had already published the Italian translation of **Proclus**' *De Sphaera* in Florence in 1573, published his grandfather's translation of Sacrobosco's *De Sphaera* in 1579.

During his stay in Bologna, Danti constructed a large meridian line in the church of San Petronio in 1575, but no trace of it remains since the south section of the building was restored in the middle of the 17th century. Danti used the meridian line for further verification of the equinoctial day, in order to contribute to the necessary calendar reform. Danti described this meridian line in a rare loose sheet entitled *Usus et tractatio gnomonis magni*.

In Bologna, Danti also constructed a number of vertical anemoscopes, instruments he invented about 1570. The only extant one, which is partially preserved, is located in the cloister of the church of San Domenico and is described in his 1578 work *Anemographia … In anemoscopium instrumentum ostensorem ventorum ….* There he relates how he came up with the idea of taking the indications given by the weathervane, which turns on a horizontal plane, and placing them on a vertical plane.

In the summer of 1577 Danti returned to Perugia, where he built two anemoscopes and also began designing the topographical map of the city and the outlying area. This work was so successful that in 1578 he was appointed to carry out the topographical survey of the entire papal state, although this project did not keep him from continuing to teach in Bologna. This work yielded the now-rare *Perusini Agri* map, printed in Rome in 1580, and the chorographic map of the *Territorio di Orvieto*, printed in 1583.

In 1580, Pope Gregory XIII called Danti to Rome as the pontifical cosmographer and mathematician, in order to reform the calendar. Danti became a member of the Reform Commission, chaired by Cardinal Guglielmo Sirleto. Danti created a meridian line on the floor of the loggia of the Torre dei Venti at the Vatican. The calendar was adjusted in 1582, and the reform was implemented in two parts. One proclaimed the new rules to follow for the future and the other set out the steps to be taken immediately to correct the errors of the past. In order to bring the vernal equinox back to 21 March, 10 days were subtracted from the year 1582, moving the calendar from Thursday, 4 October, to Friday, 15 October.

Danti was accepted as a member of the *Accademia di San Luca* in Rome in 1583 and in the same year he was named Bishop of Alatri in central Italy. In 1586, he participated in various engineering works, such as the restoration of the port of the Roman Emperor Claudius at Fiumicino, and the transfer of the Vatican obelisk to align it with Saint Peter's Basilica. Working with the architect Giovanni Fontana, Danti's specific task was to mark the solstices and equinoxes at the base, as well as the winds, thus treating the obelisk as if it were a giant gnomon. On his journey back to Alatri, Danti caught pneumonia in Valmontone and was brought back to his bishopric, where he died.

Danti was a passionate scholar of all kinds of instruments of observation. His most important works include those on the astrolabe (*Dell'uso e della fabbrica dell'astrolabio*), the anemograph (*Anemographia*), and the trigometer (*Trattato del radio latino, instrumento giustissimo*). In the second edition of his treatise on the astrolabe, Danti offered a highly detailed description of nine other astronomical instruments in use during the era.

Fabrizio Bònoli

Alternate name

Rainaldi, Carlo Pellegrino

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Dārandawī: Muḥammad ibn ʿUmar ibn ʿUthmān al-Dārandawī al-Ḥanafī

Born **Dārende near Malatya, (Turkey), 1739**
Died **Istanbul, (Turkey)**

Dārandawī, philosopher, logician, *mufassir* (scholar of Qur'ānic exegesis), and astronomer, became known for preparing a perpetual calendar as well as for his studies on the relation between astronomy and religion. After receiving his elementary education in his home region, he took courses in the town of Marʿash from Sāchaqlı-zāde Muḥammad al-Marʿashī (died: 1733), one of the most important Ottoman teachers (*mudarris*) of the time. Dārandawī came to Istanbul during Sultan Aḥmad III's reign and worked as *mudarris* in various schools (*madrasa*). Furthermore, he administered Aḥmad III's private treasury. Dārandawī died during the reign of Maḥmud I.

Dārandawī, as a versatile Ottoman *mudarris* who lived during the Tulip Period (1718–1739), participated in various scientific and cultural activities. Out of the committees founded by the Grand Vizier Newshehirli Dāmād Ibrāhīm Pasha for the translation of scientific and literature books into Turkish, he worked in the one responsible for the translation of Badr al-Dīn al-ˤAynī's (died: 1451) *ˤIqd al-jumān fī tarīkh ahl al-zamān*, an encyclopedia dealing with a number of sciences such as cosmology, astronomy, geography, zoology, and history. It consisted of 24 volumes, each volume being approximately 200 pages. Furthermore, in the *madrasa*s where Dārandawī worked, he trained many important students of the future such as Ālashahīrlī ˤUthmān ibn Ḥusayn. Dārandawī was a preeminent scholar in the cultural circles of the time, especially in fields such as Qur'ānic exegesis (*tafsīr*), the science of disputation (*ˤilm al-munāẓara*), the philosophy of logic and language, astronomical instruments, the knowledge of timekeeping *(ˤilm al-mīqāt*), and religious astronomy. His works of logic included *al-Tafriqa bayn madhhab al-muta'akhkhirīn wa-bayn al-qudamā' (al-mutaqaddimīn) fī al-qaḍiyya wa'l-taṣdīq* (Süleymaniye Library, Yazma Bağışlar MS 60), *Risāla fī Ḥall mushkilāt mabāḥith al-taˤrīf* (Süleymaniye Library, Hafid Efendi MS 160), *Risāla fī ajzā' al-qaḍiyya* (Süleymaniye Library, Bağdadlı Vehbi MS 895), *Risāla fī imkān al-ˤāmm* (Süleymaniye Library MS 449), *Risāla fī Mabāḥith al-wasīṭa* (Ali Emiri, Arabi MS 352), and *Risāla fī Ashkāl arbaˤ fī al-manṭiq* (Köprülü Library, Ahmet Pasha MS 352). In them, he focused on definition, proposition, judgment, and the relation between propositional possibility (*imkān*) and the physical world. Dārandawī criticized the opinions of the theologians (*mutakallims*), tending more toward **Ibn Sīnā**'s methods in these subjects.

Dārandawī was interested in the relation of religion and science and put a special emphasis on the relation between religion and astronomy. Working within the paradigm of his time and with a consideration of the religious dimensions, he wrote a book, at the request of his students, entitled *Risāla fī Ḥall mushkilāt masā'il thalāth* (in Arabic) (Kandilli Observatory MS 107), in which he attempted to answer three astronomical questions that Kātib Čelebī (died: 1657) had previously asked Shaykh al-Islām Bahā'ī Efendi al-**ˤĀmilī**, who had tried to answer them at the beginning of the 17th century in his work entitled *al-Ilhām al-muqaddas min al-fayḍ al-aqdas* (in Turkish) (Süleymaniye Library, Reisülküttab MS 1182/4). The first question is related to the length of daylight and night at the North Pole; the second concerns the possibility of sunrise in the west, and whether it can be explained through astronomy or not; and the third one is about the sacred direction to Mecca (*qibla*). This book's importance lies in the way it deals with science and religion and its use of Western European ideas. This book of Dārandawī exerted a considerable influence in Ottoman scientific circles. Following him, ˤAbd al-ˤAzīz al-Raḥbī (died: after 1770) examined the second question in detail in his book entitled *Kashf al-ˤayn ˤan intibāq al-mintaqatayn* (in Arabic) (Iraq Museum MS 12648). Aḥmad ibn Ḥusayn ibn Aḥmad al-Gīridī (alive: 1768), translated Dārandawī's book into Turkish under the name *Ḥall-i mushkilāt-i arbaˤa*, with revisions and some additions, and presented it to Sultan Muṣṭafa III. Gīridī criticized the noted astronomer **Taqī al-Dīn** with respect to the second question (Süleymaniye Library, Aşir Efendi MS 418/4).

In another work on timekeeping entitled *Risāla fī al-Rubˤ al-mashhūr bi-'l-muqanṭarāt* (in Arabic), Dārandawī examined an astronomical instrument called *al-rubˤ al-muqanṭarāt* (Yusuf Ağa MS 7225/14). The book, prepared for practical use, explains how to use the instrument: to calculate prayer times, the adjustment of which was considered necessary in Islamic civilization to attain perfection in religious, administrative, and social life; to determine the geometrical–trigonometric aspects of the Kaaba in Mecca; and to find the beginnings and ends of days and months, especially the holy month of Ramadan, which has particular importance for religious practices. There are about 30 extant copies, and their distribution indicates that it was widely used in two important Ottoman cities, Istanbul and Cairo.

Dārandawī's most important astronomical work, for both Ottoman–Islamic and Western astronomical history, is his *Taqwīm-i dā'imī* (in Turkish), known also as *Rūznāme* (Kandilli Observatory MS 440). This calendar, designed for perpetual use, was prepared for Istanbul, the capital city of the Ottoman State. The work can be regarded as the continuation of a tradition of such *Rūznāme*s (calendars) first prepared by Muṣliḥ al-Din Muṣṭafa ibn Aḥmad al-Ṣadrī al-Qunawī' (died: 1491), known as Shaykh Wafā', who lived during the reigns of Sultan Muḥammad II, the Conqueror, and Sultan Bāyazīd II. Dārandawī's tables were arranged for each degree of the solar longitude. In the book, all the time periods of a day, such as dawn, sunrise, morning, *kuşluk* (time between morning and noon), noon, first and second afternoon, evening, and night, as well as the time that the Sun is on the azimuth of Mecca, are stated in units of hour and minute for longitude 41°. On the other hand, the parameters used to determine dusk are based on the works of the two important figures of the Islamic tradition of timekeeping: **Khalīlī** and **Ibn al-Shāṭir**.

Albert Toderini, who visited Istanbul in 1781–1782, states that the *Taqwīm* was also known in Western Europe. Toderini, noting that the *Taqwīm* was translated by a Russian and sent to Saint Petersburg, says that he read that copy. According to him, the precision of the work extended its usefulness and surpassed previous books written on the same subject. David King notes that most extant copies of Shaykh Wafā's *Rūznāme* do not contain prayer tables; King, for example, says that G. H. Velschii's book on Turkish and Persian almanacs, published in Latin in 1676, similarly left out these prayer tables in the final part of the book where he presented Shaykh Wafā's *Rūznāme*. According to King, the reason for this is that Dārandawī's *Taqwīm* was more meticulous and precise. Thanks to its reputation, the *Taqwīm* was republished in 1787 by M. D'Ohsson in his *Tableau Général de l'Empire Ottoman*.

Dārandawī has another astronomical book entitled *Sharḥ-i Rūznāme* (in Turkish), which awaits study. This is most probably the commentary of the *Taqwīm* (Atatürk University, SÖ, MS 18824).

İhsan Fazlıoğlu

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Darquier de Pellepoix, Antoine

Born **Toulouse, France, 23 November 1718**
Died **Toulouse, France, 18 January 1802**

Toulouse deep-sky observer Antoine Darquier discovered the Ring Nebula (M57) in 1799, using a small refractor, narrowly beating out countryman **Charles Messier**.

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Darwin, George Howard

Born **Down House, Kent, England, 9 July 1845**
Died **Cambridge, England, 7 December 1912**

The details of the Moon's evolutionary history were most clearly elucidated not by the students of its surface features but by mathematicians who built on the recognition that tidal forces had retarded the Earth's rotation. These same forces, it was realized, would have slowed the Moon's rotation into synchrony with its period of revolution. The mechanism and the stages of this process were most elaborately worked out by Cambridge mathematician George Darwin.

The second son of the great evolutionist Charles Robert Darwin, George attended Trinity College, Cambridge University, graduating as second wrangler in 1868. Afterward, he studied law and was admitted to the bar but never practiced. In 1883, Darwin was appointed Plumian Professor of Astronomy at Cambridge University, a post he held for the rest of his life. There, he became a junior colleague of the most influential British physicist of that time, **William Thomson** (Lord Kelvin). Lord Kelvin's calculations of the life span of the Earth (from considerations of its rate of cooling and the lifespan available to the sun if gravitational contraction were, as Kelvin thought, its only source of energy) had been an "odious spectre" for Charles Darwin's theory of biological evolution (which seemed to require hundreds of millions of years). Ironically, it was at Lord Kelvin's behest that George Darwin adopted the theory of tides as his own special subject on which he was destined to leave his mark. Darwin married Maud du Puy of Philadelphia in 1884; the couple had four children.

Darwin first announced his theory in 1878 and published a long memoir on the subject a year later. Because of the gravitational attraction of the Moon, the liquid masses of the oceans are slightly bulged on the near and far sides of the Earth relative to the Moon. In effect, the Moon holds in position a portion of the oceans. Beneath these tidal bulges, the globe of the Earth rotates. Although water is a reasonably good lubricant, particularly when it is deep, it is not altogether without friction when dragged over shallow seabeds (like the Irish and Bering seas) by the Earth's diurnal rotation. Because of this tidal friction, the Earth suffers a braking action that slows its rate of axial rotation, lengthening the day by a miniscule fraction of a second per century. Moreover, since action and reaction are equal, as the Moon pulls on the bulging oceans, the oceans tug in return on the Moon, imparting energy to it and causing it to spiral slowly outward as the Earth's rotation slows.

Darwin calculated that after the lapse of indefinitely long ages, a stable configuration will be achieved when the Moon revolves around the Earth in about 55 days. In that inconceivably remote future, the Earth's axial rotation will also have been slowed to 55 days. But one could equally well run the cosmic clock backward. In the past, the Earth must have spun more rapidly on its axis, and the Moon must have circled much closer than it does now. At some point, the Moon's period of revolution becomes equal to the Earth's period of rotation. Near that point, Darwin wrote, the solution to the equations became unstable, "in the same sense in which an egg when balanced on its point is unstable; the smallest mote of dust will upset it, and practically it cannot stay in that position."

What had preceded this unstable condition? "It is not so easy," Darwin admitted, "to supply the missing episode. It is indeed only possible to speculate as to the preceding history." Darwin suggested that the Earth and Moon had once been part of a common molten mass that broke up due to the combined action of the tides raised by the Sun and the primordial object's rapid rotation. He attempted to estimate the minimum time at which the Moon had undergone "fissi-partition" from the proto-Earth.

At the present time, friction in the shallow seas is the most efficient mechanism of dissipating tidal energies, but when the primordial Earth was hot and plastic, tides in the body of the Earth itself would have been far more pronounced. From his belief in the "preponderating influence of the tide," Darwin found himself able to account for many peculiarities of the Earth–Moon system.

While Darwin himself believed that the cavity left behind when the Moon fissioned from the Earth would have quickly closed up, the Reverend **Osmond Fisher**, rector of Harlton near Cambridge and author of *The Physics of the Earth's Crust* (1881), disagreed. Most of the material shorn off to form the Moon would have been of the lighter continental variety, he argued, rather than the denser oceanic crust. Its departure would have left scars, including the Pacific Basin. Among the most ardent early supporters of Fisher's theory was American geologist Clarence Dutton.

Thomas A. Dobbins

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Daśabala

Flourished **(Rajasthan, India), 1055–1058**

Daśabala, who styled himself as a Bodhisattva, was a Buddhist astronomer who flourished in the 11th century. From statements made by him in his works, we learn that he was the son of Virocana of the Kāyastha class and of the Valabha clan. He eulogized King Bhoja of the Paramāra dynasty of Rajasthan who was a major patron of contemporary scholars.

Daśabala was the author of two works: the *Cintāmaṇisāraṇikā* (1055) and a larger treatise, the *Karaṇakamalamārtaṇḍa* (1058). These reveal Daśabala to be a follower of the Brāhma School, one of four principal schools of Hindu astronomy during the classical period (late 5th to 12th centuries). Both texts proved extremely useful for making astronomical computations and were couched in verse form for easy memorization of the rules.

The *Cintāmaṇisāraṇikā* is divided into six sections, and formulates tables for the daily correction of positions of the Sun and Moon, for the equation of time, and for other calendrical functions.

The *Karaṇakamalamārtaṇḍa* is a comprehensive treatise that describes all of the principal aspects of astronomy. It consists of 10 sections relating chiefly to the calculation of planetary positions, lunar and solar eclipses, the lunar crescent, and planetary conjunctions, along with an enumeration of the 60-year cycle of Jupiter. In short, this work provides all necessary information on standard computations performed in Indian astronomy.

Ke Ve Sarma

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Davis, Charles Henry

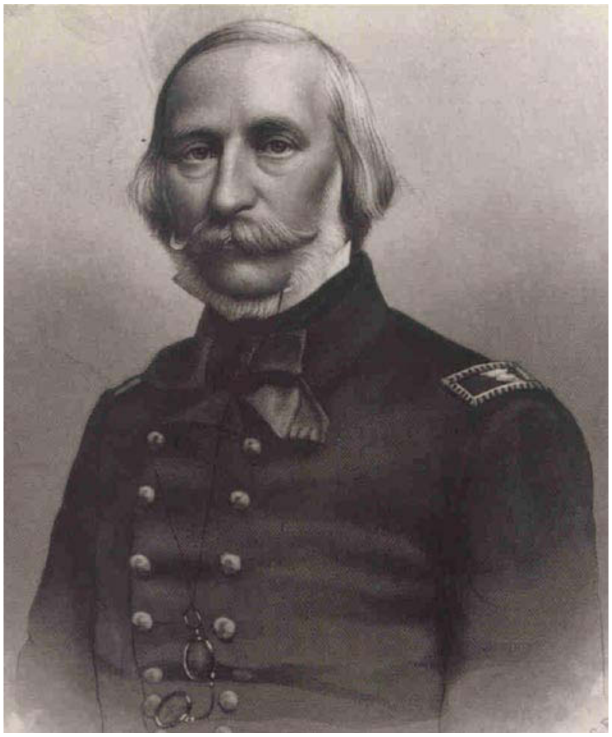
Born **Boston, Massachusetts, USA, 16 January 1807**
Died **Washington, District of Columbia, USA, 18 February 1877**

In producing the *American Ephemeris and Nautical Almanac*, Charles Davis successfully argued that basic research on planetary motions was a necessity.

Davis was educated at Boston Latin School, and graduated from Harvard University in 1825. He had left college in 1823, however, to enter the United States Navy, and was made lieutenant in 1827. After about 17 years of sea duty, he was assigned to the United States Coast Survey in April 1842, and undertook hydrographic work. Davis is best known as the first superintendent of the American Nautical Almanac Office, 1849–1855. Although his role as the founder of the office has been exaggerated at the expense of **Matthew Maury**, Davis certainly played a key role as the first superintendent, and again from 1859 to 1861.

Davis was also the third superintendent of the Naval Observatory (1865–1867), and again from 1874 until his death in 1877. In this capacity, he revived astronomy at the observatory in the post-Civil-War years, and became involved in preparations for the American expeditions for the transit of Venus, among much other administrative and scientific work. Davis also served with **Joseph Henry** and **Alexander Bache** on the permanent Commission that led to the founding of the National Academy of Sciences [NAS] in 1863. He achieved the rank of commander in 1854, commodore in 1862, and rear admiral in 1863; the latter two ranks were granted while he was actively engaged in the Civil War.

Davis's son, Captain Charles H. Davis II, also served as superintendent of the Naval Observatory at the turn of the century. The biography



of his father, which he wrote, is informative, but must be read keeping in mind that it is a family-written biography. Davis's papers relating to the American Nautical Almanac Office may be found in the records of the United States Naval Observatory, Record Group 78, National Archives, Washington, DC, and in the Naval Historical Foundation Collections of the Library of Congress, Manuscript Division.

Steven J. Dick

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Davis, Raymond, Jr.

Born **Washington, USA, 14 October 1914**
Died **Blue Point, New York, USA, 31 May 2006**

American radiochemist/physicist Raymond Davis conceived, built, and ran the first experiment to detect neutrinos from the Sun. His work provided the first direct experimental confirmation that the Sun produces energy by thermonuclear fusion of hydrogen to helium.

Davis received BS and MS degrees in physical chemistry from the University of Maryland in 1937 and 1940, respectively. In 1942, he earned a Ph.D. from Yale University also in physical chemistry. Davis served in the United States Army from 1942 to 1946, after which he worked for the Monsanto Chemical Company for 2 years. In 1948, he joined the staff at Brookhaven National Laboratory in Upton, New York, and stayed there until his retirement in 1984. In 1985, Davis joined the Department of Physics and Astronomy at the University of Pennsylvania.

Going against common wisdom in the physics community that the detection of neutrinos from reactors by Fredrick Reines and Clyde Cowan was at the limit of what could be achieved, Davis constructed a neutrino detector 1 mile underground in the Homestake Gold Mine at Lead, South Dakota. The subterranean location was chosen to reduce the background flux produced by cosmic rays.

The experiment was a radiochemical design. The 680-ton detector consisted of 100,000 gal of perchloroethylene, a common chlorine-rich dry-cleaning fluid that was available cheaply in large quantities, due to its industrial use. Neutrinos from the Sun induced the chlorine-37 atoms to convert to gaseous argon-37, which was flushed from the detector every few months and counted by its radioactive decay.

For 20 years, Davis detected only one-third of the predicted flux of solar neutrinos, leading to the "solar neutrino problem." Since Davis's experiment was only sensitive to the highest-energy neutrinos emitted by the Sun, some scientists believed that the problem was due to the center of the Sun being very slightly cooler than in the existing models or to experimental error. In the 1980s, Japanese physicists built a water Cherenkov-radiation detector that had been intended to see proton decay infact confirmed Davis's result. Subsequent experiments in Italy, Russia, and Canada showed that the apparent neutrino deficit was causing neutrinos were changing "flavor" from the electron type, to which Davis's experiment was sensitive, to μ- or τ-type neutrinos due to the Mikheyev, Smirnov, and Wolfenstein [MSW] effect. In MSW, the mass eigenstates of neutrinos are linear combinations of the flavor eigenstates, and neutrinos change flavor by interacting with matter in the Sun. This result also demonstrates that neutrinos have (a very small) mass. Davis is clearly the father of the modern field of "neutrino astrophysics."

Davis received the Boris Pregel Prize of the New York Academy of Sciences in 1957, the Comstock Prize from the National Academy of Sciences in 1978, and the American Chemical Society Award for Nuclear Chemistry in 1979. He was elected to the National Academy of Sciences in 1982 (Astronomy). Davis received the Tom W. Bonner Prize in 1988 and the W. K. H. Panofsky Prize in 1992 from the American Physical Society, the Hale Prize from the American Astronomical Society in 1996, the Bruno Pontecorvo Prize from the Russian Academy of Sciences in 1999, the prestigious Wolf Prize in 2000, and the National Medal of Science in 2002. Finally in 2002, he shared the Nobel Prize in Physics with Masotoshi Koshiba, who developed the Japanese neutrino detector known as Kamiokande, and X-ray astronomer Riccardo Giacconi.

Edward Baron

Selected Reference

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Davis Locanthi, Dorothy N.

Born **East Saint Louis, Illinois, USA, 19 April 1913**
Died **Glendale, California, USA, 27 September 1999**

American astronomer Dorothy Davis Locanthi studied the spectra of M- and S-type stars and, with **Jesse Greenstein** at the California Institute of Technology, strove to produce a high-dispersion spectral atlas of (the M giant) Antares, comparable with those available for the Sun.

Alternate name

Locanthi, Dorothy N.

Selected Reference

Osterbrock, Donald E. (2000). "Dorothy N. Davis Locanthi, 1913–1999." *Bulletin of the American Astronomical Society* 32: 1677–1678.

Dawes, William

Born **Portsmouth, England, 1762**
Died **Antigua, 1836**

William Dawes, a lieutenant in the Royal Marines, sailed to the Australian penal colony with the First Fleet in 1779. On the recommendation of **Nevil Maskelyne**, Dawes established the first observatory in Australia, near Sydney in 1788, and conducted a valuable series of longitude determinations as well as general astronomical observations. Dawes later served as Governor of Sierra Leone. His son **William Rutter Dawes** achieved lasting fame as a double-star observer.

Thomas R. Williams

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Dawes, William Rutter

Born **London, England, 19 March 1799**
Died **Haddenham, Buckinghamshire, England, 15 February 1868**

William Rutter Dawes is known for the empirical formula he devised to determine the resolving power of a telescope (Dawes Limit), his extraordinarily keen vision that earned him the sobriquet "eagle-eyed," and the care and skill with which he conducted his observations of celestial objects. These qualities distinguished him as one of the finest observational astronomers of his day.

Dawes was born at Christ's Hospital, where his father **William Dawes** was mathematical master. William Dawes had been Government Astronomer on the first expedition to Botany Bay in 1787, and had married Judith Rutter in 1792 after his return to England. William Rutter lost his mother at an early age, and following his father's third official posting to Sierra Leone as that colony's Governor in 1801, was sent to live with his grandfather in Portsmouth. In 1807, William Rutter's care became the responsibility of Reverend Thomas Scott of Aston-Sandford, Buckinghamshire, with whom he resided until the return of his father in 1811, at which time he was placed in Charterhouse School. Two years later, responsibility for his welfare again reverted to the Reverend Scott when William Rutter's father and elder sister Judith left England to take up work as antislavery missionaries in Antigua. Thus began a period of study terminated only when Scott died in 1821.

The young Dawes' doubts about certain tenets of the Anglican church, a calling to which he seemed peculiarly suited, induced him to substitute medicine for the clerical career his father desired for him. Having passed through the normal course of study at Saint Bartholomew's Hospital, London, Dawes settled as a medical practitioner at Haddenham, Berkshire, marrying Mrs. Scott, the widow of his tutor. In spite of the great disparity in age, the union contributed greatly to Dawes' well-being and happiness.

In 1826, Dawes precipitously abandoned his practice at Haddenham and moved to Liverpool to attend to his sister Judith, who had returned from Antigua in desperate condition as a victim of yellow fever. There, Dawes' interest in astronomy, inherited from his father and continued during his stay with Scott, widened and deepened. Having obtained the loan of a volume of *Rees's Encyclopedia*, he copied out **William Herschel**'s catalogs of double stars. Armed with those lists and a copy of the French edition of **John Flamsteed**'s *Atlas* (given by **Nevil Maskelyne** to his father prior to the latter's departure for Botany Bay in 1787), Dawes observed on almost every fine night when his uncertain health would permit. With a small refracting telescope of 1.6-in. aperture, mounted at an open window of his house, Dawes made accurate diagrams of binary stars. With this arrangement he was able to distinguish the companion stars of Castor, Rigel, Polaris, γ Virginis, and many others. About this time Dawes came in contact with fellow amateur **William Lassell** with whom he struck up a friendship that was to last for the rest of their lives.

While in Liverpool, Dawes' interest in holy orders revived, perhaps not only as a result of his sister's condition and likely death but also under the influence of Dr. Raffles, who was for many years the minister at the Independent Chapel, Great George Street, in Liverpool. Although his scruples once again intervened, Dawes was eventually prevailed upon to assume charge of a small congregation at Ormskirk, a modest-sized town some 15 miles north of Liverpool in Lancashire.

At Ormskirk, Dawes erected his first observatory, a modest structure housing a 5-ft. Dollond refractor of 3.75-in. aperture and equipped with a filar micrometer. His first published observation was of an occultation of Aldebaran seen from Ormskirk on 9 December 1829. However, Dawes devoted himself to the observation and measurement of double stars. This was a subject to which his acute vision and attentive habits were particularly adapted.

His "Micrometrical Measurements of 121 Double Stars …," in the *Monthly Notices of the Royal Astronomical Society*, documented this effort well. Dawes was elected a fellow of the Royal Astronomical Society on 14 May 1830.

But while Dawes enjoyed increasing success as an amateur astronomer, his private life fell apart. His wife, who was much older than he, died, and his own health, which had always been uncertain, broke down. Accordingly, he resigned the Ormskirk ministry, and in the autumn of 1839, he accepted the charge of the private observatory erected by the wealthy wine merchant George Bishop at South Villa, Regent's Park, London. At South Villa, Dawes continued his double-star work, detecting orbital movement in ε Hydrae and, independent of the observers at Pulkovo, in γ Andromedae.

Three years before his death in 1868, in a communication to *The Astronomical Register*, Dawes gave indications of a tense relationship between himself and Bishop. Dawes objected strenuously to the fact that measurements of about 250 double stars made between 1839 and 1844, which Bishop had published in 1852 as part of his *Astronomical Observations Taken at the Observatory South Villa*, were in fact not made by Bishop but instead were Dawes' own observations. The souring of this relationship may explain why, in 1844, Dawes terminated his engagement at South Villa and moved to Cranbrook, in Kent, not far from Hawkhurst where his friend **John Herschel** lived. That he was enabled to make this change can be ascribed to his remarriage, in 1842, to Mrs. John Welsby of Ormskirk, the widow of a wealthy solicitor.

At Cranbrook, Dawes set up an observatory that included a 2-ft.-diameter transit circle by Simms, and a clockwork driven Merz & Mahler equatorial of 6.5-in. aperture and 8.5-ft. focal length. With these he worked tirelessly until forced by headaches and asthma to retire to Torquay, where he even thought of abandoning astronomy. In 1850, following an improvement in his condition, Dawes resumed his astronomical pursuits at Wateringbury, near Maidstone, where on 25 and 29 November, of that year, independent of **George Bond** in America, he detected the faint, dusky crepe ring of Saturn.

Finally in 1857, Dawes removed his observatory to Hopefield, Haddenham, near Thame, where he remained for the rest of his life. Dawes was highly regarded for the medical service he dispensed freely to the impoverished residents of the town. Here, in May 1859, he reinforced his instrumentation with an equatorial refractor of 8.25-in. aperture, by **Alvan Clark** of Cambridgeport, Massachusetts, and 6 years later an 8-in. Cooke achromatic. His second wife died in 1860, but in spite of his own rapidly deteriorating health Dawes continued to observe until 1867.

Apart from his work on double stars and a number of comets, Dawes made useful observations of Mars, from which **Richard Proctor** constructed an albedo map of the planet (1867). Dawes verified the reality of Encke's Division in the outer ring of Saturn (1843), affirmed the semitransparency of the inner dusky ring, and observed ring phenomena at the edge-on presentation of 1848. Using a solar eyepiece of his original design, Dawes detected fine structure and rotary movement in sunspots, and saw a facula projected above the limb of the Sun. He also refuted the "willow leaf" aspect of the solar granulation reported by **James Nasmyth**, and vividly described the crimson prominences at the total solar eclipse of July 1851, which he observed from Sweden with **John Hind**.

As Alvan Clark's first major customer, Dawes brought the skill of the American telescope maker to wide notice in Europe. Dawes bought five Clark lenses, including two mounted in telescopes. With them, he took his lifetime total of binary-star measurements to almost 3,000. Dawes' "Catalogue of Micrometrical Measures of Double Stars" includes the description of what is universally known as the Dawes limit.

Dawes received the Gold Medal of the Royal Astronomical Society in 1855 and was elected a fellow of the Royal Society in 1865.

Richard Baum

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Dawson, Bernhard

Born ***circa* 1891**
Died **18 June 1960**

On 8 November 1942, Bernhard Dawson discovered Nova Puppis, one of the brightest nova of the 20th century, at the Córdoba Astronomical Observatory (La Plata, Argentina). The light curve of CV Pup was prepared by **Edison Pettit**.

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de la Lande, Joseph-Jérôme

➜ **Lalande, Joseph-Jérôme**

De la Rue, Warren

Born **Isle of Guernsey, United Kingdom, 15 January 1815**
Died **London, England, 19 April 1889**

Warren de la Rue pioneered the application of photography to the study of the Moon and Sun, in the process demonstrating the value of an equatorially mounted, clock-driven reflecting telescope as a camera, techniques that greatly accelerated the evolution of the new science of astrophysics. The son of Thomas de la Rue, a printer, and Jane (*née* Warren), de la Rue was educated at the Collège Sainte-Barbe in Paris and later studied with the noted chemist August Wilhelm Hofmann in London. While still in his youth, de la Rue joined his father's printing business, where he showed a talent for mechanical innovation. He was among the first printers to adopt the electrotyping process and was coinventor (with Edwin Hill) of the envelope-making machine.

De la Rue's earliest scientific contributions were in the field of chemistry. In 1836, he published his first paper, describing an improvement to the Daniell cell, a form of copper–zinc battery. He helped edit an English version of the first two volumes of the *Jahresbericht der Chemie* by Justus von Liebig and Heinrich Kopp. Much later, between 1868 and 1883, he conducted experiments on electrical discharges in gases, accumulating a wealth of data but resulting in no theoretical "advances."

James Nasmyth, inventor of the steam-driven pile driver and a friend of de la Rue, introduced him to astronomy in the late 1840s. Nasmyth was a noted lunar observer whose detailed drawings of the Moon's surface brought him wide acclaim. Impressed by Nasmyth's achievement, de la Rue built a small observatory at Canonbury, England (later moved to Cranford in Middlesex), where he installed a Newtonian-style reflecting telescope of his own design, incorporating a 13-in.-diameter speculum-metal mirror. Nasmyth provided the cast speculum-metal disks from which de la Rue ground and polished excellent mirrors for his telescope. The perfection of de la Rue's mirrors was due in no small part to the mirror-making machine he built after examining similar machines built by Nasmyth and especially a machine designed and constructed by **William Lassell**. De la Rue's machine more completely controlled the relative motions of the mirror and the tool against which it was being ground and polished, ensuring that all diameters were equally and uniformly traversed in the course of the grinding and polishing operations.

Like Nasmyth, de la Rue's first foray into astronomy involved the hand rendering of the Sun, Moon, and planets. In 1850, he published a highly praised drawing of Saturn. De la Rue turned his attention to celestial photography in late 1852 after viewing the lunar daguerreotypes of Harvard astronomer **William Bond** and photographer John Adams Whipple at the 1851 Crystal Palace exhibition in London. De la Rue adopted the new wet-collodion photographic process with good result. After extensive experimentation and the installation, in 1857, of a clock drive to his telescope, he obtained a series of exquisitely detailed lunar images. The images, although small, were so clear that they could be enlarged to almost 8 in. In particular, de la Rue was lauded for his extraordinary stereoscopic photographs of the Moon, which revealed surface features never before seen. A bound set of reproductions of de la Rue's lunar photographs was published in 1860. De la Rue's photographs played a major role in British efforts to settle questions about the possible volcanic origin of lunar features, and detection of continuing volcanic activity on the Moon. He participated in a panel of scientists charged with considering this specific question. The panel included, among its 11 members, **William Parsons**, Third Earl of Ross, and Sir **John Herschel**.

Following a recommendation by John Herschel in 1847 (repeated more forcefully in 1854), de la Rue developed a photoheliograph, a specialized telescope with which he maintained a daily photographic record of sunspot activity. The instrument, a refractor of 3-in. aperture, projected a magnified image of the Sun through a grid that was recorded as part of the solar image on a wet-collodion plate. The necessarily short exposure time was controlled with a shutter. The photoheliograph, installed at Kew in 1858, produced images of the solar disk that revealed details that could not be observed visually. The daily solar photographic survey was continued at Kew until 1872, at which time it was transferred to Greenwich as the first step taken by the Royal Observatory in the emerging field of astrophysics.

The photoheliograph was temporarily removed from Kew by de la Rue to photograph the total solar eclipse of 18 July 1860, from Rivabellosa, Spain. De la Rue's photographs, along with others obtained about 250 miles farther east on the path of the total eclipse by **Angelo Secchi** and others, demonstrated conclusively that the luminous, "flame-like" outbursts (now known as prominences) seen during eclipse were of solar, not lunar, origin.

In 1861, de la Rue demonstrated through stereoscopic imagery that sunspots were depressions in the Sun's atmosphere. He also achieved a modest measure of success with stellar photography in the 1860s. Through his own detailed reports of his procedures to various scientific organizations, de la Rue paved the way for subsequent photographic progress by his astronomical colleagues.

De la Rue was president of the British Chemical Society from 1867 to 1869 and in 1879/1880. He was elected a fellow of the Royal Society in 1850 and later a corresponding member of the French Academy of Sciences. He served as president of the Royal Astronomical Society from 1864 to 1866. For his contributions to the practice of celestial photography, de la Rue received the Royal Astronomical Society's Gold Medal in 1862, the Royal Society's Royal Medal in 1864, and the Lalande Prize in 1865. In 1840, de la Rue married Georgiana Bowles; they had four sons and a daughter.

Alan W. Hirshfeld

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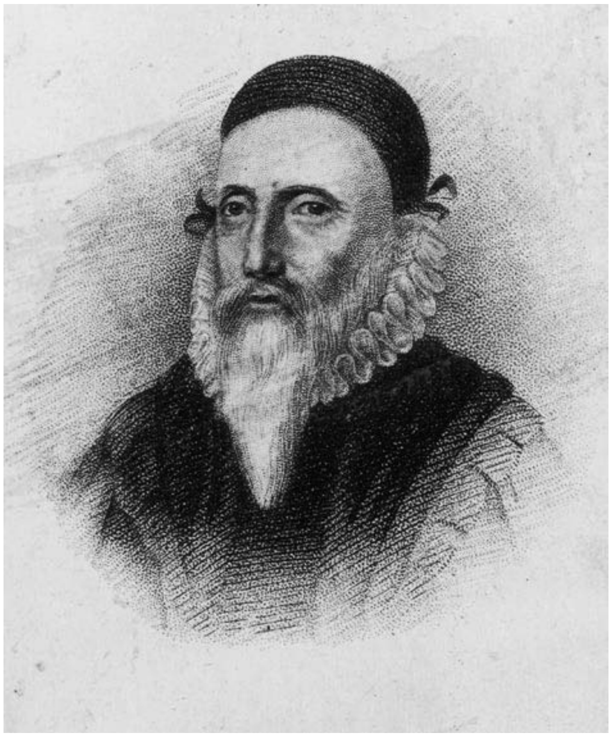
Dee, John

Born **London, England, 15 July 1527**
Died **Mortlake, (London), England, December 1608**



John Dee is notorious for his alchemy, mysticism, and astrology; famous for his influence in the affairs of the Tudor court; and important to the history of astronomy as a government adviser on navigational matters and the calendar.

Dee's father, Roland Dee, was a mercer and a "gentleman server" (minor official) at the court of Henry VIII. His mother was Jane, daughter of William Wild. Dee attended Chantry School in Essex and Saint John's College, Cambridge (BA: 1545). He became a fellow of Trinity College in 1546 (MA: 1548) and studied at Louvain University from 1548 to 1551, with **Gemma Frisius** and **Gerhard Kremer**. At Louvain, Dee was a tutor in mathematics and geography. Returning to England, he cultivated influential social circles, tutoring the Earl of Warwick and Sir Philip Sidney, and gaining the patronage of the Duke and Duchess of Northumberland. (Dee was tutor of their children, including Robert Dudley, the future Earl of Leicester.) He gained a yearly pension from King Edward VI and significant patronage from the Earl of Leicester.

During the reign of Queen Mary, Dee cast horoscopes for her and her sister, Elizabeth. He was accused of heresy and of directing enchantments toward Mary's life, and was imprisoned for a year before he was cleared. When Elizabeth succeeded her sister, Dee was commissioned to select an astrologically auspicious date for her coronation, and was declared Royal Astrologer. As Queen, Elizabeth protected him from further slanders about being a magician, so that he could pursue his "rare studies and philosophical exercises." As court astrologer, he claimed to have put a hex on the Spanish Armada and caused the bad weather that wrecked the fleet.

From 1555 for 30 years, Dee was a consultant to the Muscovy Company, founded by the navigator and explorer Sebastian Cabot to exploit a monopoly of Anglo–Russian trade. It had as one of its aims the search for the northeast and northwest passages. Dee prepared nautical information, including charts for navigation in the polar regions. The first mathematician to apply Euclidean geometry to navigation, he edited (and possibly wrote parts of) the Billingsley translation of Euclid in 1570, adding a prophetic preface in justification of mathematics as the foundation of the sciences. Dee instructed a number of pilots, including Richard Chancellor, Stephen and William Borough, Martin Frobisher, Humphrey Gilbert, John Davis, and Walter Raleigh, and may have been an advisor to Drake's voyage.

As part of a planned, larger work on the history of discoveries, Dee wrote a pamphlet (1577), *Rare studies and philosophical exercises* (known from later key words in the title as *The Perfect Arte of Navigation*) as propaganda for the British Empire. In this role as a visionary for the British Empire, he created the personification of Britannia and developed a plan for the British Navy. In 1580, Dee was commissioned by Elizabeth to establish the legal case for "reacquiring" the colonies of North America. He traced the legal history of the British colonization of America back to Madoc, a Welsh Prince of the Middle Ages, who is said to have taken a group of people to New England to establish the first colony from Britain. Other consulting work for the crown included reports on Pope Gregory XIII's corrections in 1582 to the Julian calendar.

As a powerful and evidently well-enough paid court intriguer, and 50 years before the foundation of the library in Oxford by Thomas Bodley, Dee built up a library of 4,000 books, said to be the largest in England, assembled from the dissolved monasteries. The books were mostly medieval science and history manuscripts, and the library was dispersed after his death. (There exists a John Dee Society; one of its aims is to reconstitute the accession list of the library.) Dee himself wrote *Monas hieroglyphia* (1564) and *Propaedeumata aphoristica* (1558), books of mysticism and astrology. In 1573, he published *Parallacticae commentationis praxosque*, a trigonometric analysis of the parallax of the new star (supernova) of 1572 (SN B Cas). He designed a large *radius astronomicus* for **Thomas Digges** to observe it.

Around 1582, Dee's interests in astrology, crystal gazing, divination, and the occult made him associate with Edward Kelly, who claimed to have discovered the alchemical secret of transmuting base metal to gold. Dee's influence began to slide downhill as he tried to understand the secrets of the Universe through angelic spirits and mystic languages. He encountered a Polish prince, Laski, and left England, going to Laski's estate in Poland. Dee went to Prague in 1584, but failed to secure hoped-for patronage from Rudolph. In fact, the Catholic Church there regarded him very suspiciously. For a number of years, until late in 1589, he was a sort of itinerant alchemist and magician around the continent. When Dee finally broke with Kelly and returned to England, he found himself in various unimportant positions. He held the rectorship of Upton-upon-Severn in Worcestershire (1553–1608) and of Long Leadenham in Lincolnshire (1566–1608), as sinecures. Queen Elizabeth granted Dee a pension that he never received. He was warden of Christ's College, Manchester (1592–1605). When James I succeeded Elizabeth, Dee was ostracized. He died in poverty.

Paul Murdin

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Delambre, Jean-Baptiste-Joseph

Born **Amiens, (Somme), France, 19 September 1749**
Died **Paris, France, 19 August 1822**

Jean Delambre made fundamental contributions to celestial mechanics and geodesy, authored a leading textbook on mathematical astronomy, and published a six-volume history of astronomy from ancient times to the 18th century. He was one of many young men that owed their careers in astronomy to **Joseph de Lalande**. After his early studies with Jacques Delille, Delambre went to Paris to study classical languages until he was hired as the tutor of a young man in Compiègne, north of Paris. Returning to the capital city as a private instructor, he attended Lalande's classes at the Collège de France and began working with Lalande, whose influence steered Delambre's career toward astronomy.

In 1790, Delambre won a competition sponsored by the Académie royale des sciences for calculating the orbit of the newly discovered planet Uranus. Delambre took into account the perturbations exerted by Jupiter and Saturn, which established his reputation as a skillful calculator of astronomical tables and a resourceful innovator of methods in celestial mechanics. In 1792, he received a second prize, which opened the academy's doors to him, just as another opportunity presented itself.

In preparation for their country's adoption of the new metric system (approved the previous year), **Jean Cassini**, **Adrien Legendre**, and **Pierre Méchain** were assigned to measure an arc of the meridian through Paris between Dunkirk, France, and Barcelona, Spain. Cassini refused the offer in 1792 for political reasons and Legendre declined because he preferred theoretical work. Delambre, as a new member of the Académie, joined the project and, together with **Michel Lefrançois**, nephew of his advisor, was assigned the easiest yet longest part: to remeasure the arc between Dunkirk and Rodez, in central France, which had already been measured and calculated. The other, shorter part was left to the more experienced Méchain, who would measure the remainder of the arc in France and the unmeasured part in Spain to which he immediately headed.

During the most dramatic period of the French Revolution, as a member of the academy and under suspicion of loyalty to the old regime, Delambre traveled the French mountains and roads. Over 3 years (1793–1796), and even with long interruptions, he finished the geodetic measurements and formed new theoretical tools for the reduction of his observations. The result was his important work, *Analytical Processes for Determining an Arc of Meridian* (1798), and numerous publications and tables in the *Connaissance de temps*. Once finished with the assignment, Delambre measured the geodetic base of Melun and also, due to Mechain's delays, was given charge of measuring the base of Perpignan.

Delambre was named to the Bureau des longitudes and the Institut National after their establishments in 1795. He gradually assumed more important institutional roles. Delambre was a prominent member of the commission that defined the length of the meter and was responsible for the custody of all accumulated materials. Shortly afterward, through the Bureau des longitudes, he was appointed to direct the Paris Observatory, but was then succeeded by Méchain. After the latter's death in 1804, Delambre was placed in charge of publishing all of the astronomical and geodetic measurements conducted to determine the meter. These appeared in a monumental work, *The Base of the Metric System* (1806–1810), along with Delambre's important autobiographical notes.

After completing these tasks, Delambre was awarded successively higher posts in French science and administration. In 1803, he was elected the first permanent secretary of mathematical sciences at the Institut National, the organization that replaced the Académie des sciences. Finally, in 1807, Delambre succeeded Lalande as professor of astronomy at the Collège de France. In 1814, after the fall of Napoleon, he was elected to membership in the Royal Council of Public Education.

As part of his work as secretary of the Institut National, Delambre published in 1810 his *Historic Report on the Progress of Mathematical Sciences since 1789*, in which he reviewed the progress in astronomy achieved during this period. Collecting his lessons from the Collège de France, he published his *Abridged Astronomy* (1813), an elementary-level textbook. The following year, his most important astronomical work appeared: *Theoretical and Practical Astronomy* (three volumes, 1814), which presented the best summary of its subject to date and replaced the previous text authored by his teacher, Lalande. Delambre's *Astronomy* became the text from which this science was studied by the following generation of French astronomers and others throughout Europe.

Starting in 1817, Delambre began to publish a monumental history of astronomy, in six volumes, that is still in use today. Its final volume, *History of Astronomy in the Eighteenth Century* (1827), was published posthumously by his student and heir of his scientific papers, **Claude Mathieu**.

Antonio E. Ten
Translated by: *Claudia Netz*

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Delaunay, Charles-Eugène

Born **Lusigny, Aube, France, 9 April 1816**
Died **at sea near Cherbourg, France, 5 August 1872**

Charles-Eugène Delaunay was a professor, director of the Paris Observatory, mathematician, and a significant contributor to lunar theory. The son of Jacques-Hubert Delaunay, a mathematics teacher, and Catherine Choiselat, Delaunay entered the École Polytechnique in 1834. Ranked first in his class 2 years later, he received the first Laplace Prize, a copy of the astronomer's complete works that is said to have prompted his interest in celestial mechanics. After turning down an offer from **Dominique Arago** to join the Paris Observatory after his mentor **Félix Savary**, from the Bureau des longitudes, said that this amounted to forfeiting his independence, Delaunay attended the École des mines, with which he stayed closely associated through the early part of his career. He married Marie-Olympe Millot in 1839, and they had a son the following year; after her untimely death in 1849, he raised his son alone and devoted himself to the pursuit of lunar motion theory.

In November 1838, Delaunay was hired by the École Polytechnique as *répétiteur* (teaching assistant), for the course on geodesy and machines, later nominated *répétiteur* of mechanics to replace **Urbain Le Verrier**, and was made professor in 1851. From 1841, he was **Jean-Biot**'s *suppléant* for the course of physical mechanics at the University of Paris (Sorbonne), whose chair Delaunay occupied in 1848.

Despite Le Verrier's opposition, Delaunay was elected at the Paris Académie des sciences in 1855. He was later nominated to the Bureau in 1867, became a fellow of the Royal Society in London in 1867, and was appointed director of the Paris Observatory after Le Verrier's dismissal on 2 March 1870. That same year, Delaunay was awarded the Gold Medal of the Royal Astronomical Society.

Above all, Delaunay was an indefatigable analytical computer. His first paper was a short note published in 1838 in Joseph Liouville's *Journal de mathématiques pures et appliquées*. Although astronomy seems to have been his early passion, Delaunay's 1841 doctoral thesis at the Sorbonne was also concerned with mathematics, namely the calculus of variations ("De la distinction des maxima et des minima dans les questions qui dépendent de la méthode des variations"). In the 1840s, he also worked on Uranus inequalities and tide theory.

"Baron of the Moon," according to Biot, Delaunay dedicated 20 years to the painstaking computations involved in the theory of its motion. Starting in 1846, he developed an original method for this problem that involved canonical equations in what are today called Delaunay variables. In 1860 and 1867, he published the two volumes on his monumental *Théorie des mouvements de la lune*, where, in this important case of the three-body problem, Delaunay expressed the longitude, latitude, and parallax of the Moon as infinite series, his results being correct to 1″ but not very practical because of slow convergence. In the language of modern-day nonlinear dynamics, he replaced the actual chaotic (nonintegrable) Hamiltonian by a nonchaotic (integrable) approximation designed to give good agreement with the real dynamics. The 461 terms in the perturbating function, sometimes developed to the ninth order, take up more than 100 pages. Delaunay's contemporaries and followers, **Simon Newcomb** and **Henri Poincaré** among others, praised this work in the highest terms. The basis for theoretical developments in analytical mechanics by Poincaré, **George Hill**, and Anders Lindstedt, Delaunay's theory introduced methods that are still in use today for the computation of artificial satellite motions.

An intense and bitter rivalry developed between Delaunay and Le Verrier. After having presented the academy with preliminary results concerning inequalities in Uranus' motion in 1842, Delaunay was criticized by Le Verrier. Because of discrepancies between **Peter Hansen**'s tables of the Moon and Delaunay's theoretical predictions, Verrier alleged to have found errors in the theory. In 1865, Delaunay suggested that they arose from a slowing of the Earth's rotation due to tidal friction, an explanation today believed to be correct.

The opposition was mostly rooted in personal resentment and struggle for the control over French astronomy. The author of two successful textbooks on mechanics and machines, *Cours élémentaire de mécanique théorique et appliquée* (1851) and *Traité de mécanique rationnelle* (1856), Delaunay had caught the attention of Emperor Napoléon III, who sought his support in rejuvenating the moribund Bureau des longitudes as counterpower to Le Verrier's observatory. Delaunay was thereby instrumental in Le Verrier's fall from grace in 1870 and was appointed in his place, despite having no experience in astronomical observation.

As director of the Paris Observatory, Delaunay was keen to transfer it outside of the city to the suburban town of Fontenay-aux-Roses, or to keep it in Paris only if Louis XIV's building were leveled. During the unrest caused by war and insurrection in 1870–1871, Delaunay courageously preserved the integrity of the institution. He had set out to reorganize the conduct of astronomical research and observation in France when he lost his life in a shipwreck as he was surveying the fortifications of Cherbourg's harbor.

David Aubin

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Delisle, Joseph-Nicolas

Born **Paris, France, 4 April 1688**
Died **Paris, France, 11 September 1768**

Joseph-Nicolas Delisle was a teacher and observational astronomer noted for his work on comet prediction and transits. Delisle was the son of Claude Delisle, a historian, and Nicole-Charlotte Millet de la Croyère. Educated at the Collège Mazarin, he developed an early interest in astronomy. Joining the Académie royale des sciences formally in 1714 (as an *associé* to **Giacomo Maraldi**), Delisle was eventually appointed to the chair of mathematics at the Collège royal in 1718. He married about 1725, but had no children.

Delisle's regular observations with his own equipment began in 1721; in the same year, he received an invitation from Peter the Great to found an observatory in Russia. From 1725 to 1747 Delisle worked at Saint Petersburg, training numerous students. Some of them later performed cartographic work intended to serve as raw material for an accurate map of the whole of Russia. In order to improve geographical longitude data, Delisle collected and published a long series of observations of the Jovian satellites at Saint Petersburg. He was especially interested in the transits of Mercury, which he tried to use for accurate determinations of the solar parallax *in lieu* of the rarer transits of Venus. After his return to Paris in 1748, Delisle resumed his observing and teaching activities; among his students were **Joseph de Lalande** and **Charles Messier**.

Practical needs caused Delisle to improve **Edmond Halley**'s planetary tables, to publish several predictions of impending solar eclipses and Mercury transits, and, most importantly, to develop an easy-to-use set of tables intended to aid in the recovery of Halley's comet (IP/Halley), combining (approximate) orbital elements and an unknown date of perihelion passage. His method, published in 1757 and for some time (*e. g.*, by **Heinrich Olbers**) associated with his name, is still of obvious benefit for the recovery of comets with known elliptical orbits but only one observed perihelion passage. Delisle's last efforts were dedicated to the preparations for the Venus transit of 1761, helping to establish worldwide cooperation for observations of this event.

Wolfgang Kokott

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Delporte, Eugène-Joseph

Born **Genappe, Brabant, Belgium, 17 January 1882**
Died **Uccle near Brussels, Belgium, 19 October 1955**

The Belgian astronomer Eugène Delporte is credited with the discovery of at least 66 asteroids in modern catalogs, and was the final authority in establishing the boundaries of constellations officially adopted by the International Astronomical Union [IAU]. Delporte studied mathematics at the Free University of Brussels, and received a doctorate in mathematical and physical sciences in 1903. He was employed the same year at the Royal Belgian Observatory at Uccle, and appointed director of the Uccle Observatory in 1936. Even after his retirement in 1947, Delporte continued observational work at Uccle. He died from a heart attack while examining a photographic plate.

Initially put in charge of time and meridian measurements, Delporte eventually specialized in the search for minor planets through systematic photography of the sky. In doing so, Delporte established a tradition continued to this day by his successors at Uccle. His first success was (1052) Belgica, the first minor planet discovered from Belgium. As of 2004, 66 minor planets discovered by Delporte had been numbered and named; two of these can make close approaches to the Earth: (1221) Armor, discovered in 1932, and (2101) Adonis, discovered in 1936 but later lost and then found again in 1977. Adonis' orbit crosses the Earth's orbit and reaches its perihelion inside the orbit of Venus.

Delporte made an independent discovery of a comet, 57P/1941 O1, on 19 August 1941. Because of the war – Belgium was then occupied by the German army – he was unaware of earlier observations by Daniel du Toit (18 July) at Bloemfontein, South Africa, and G. Neujmin (25 July) in the Crimea (then part of the Soviet Union). Delporte could only communicate his discovery to institutes abroad after receiving special military permission, which he finally obtained with the help of a German officer who had been a geographer before the war. The comet is now known as 57P/du Toit-Neujmin-Delporte.

Delporte is perhaps best known for his work in establishing the official boundaries of the constellations. In 1922, the IAU fixed the number of constellations at 88. At that time, Delporte and his fellow countryman L. Casteels proposed to lay down arcs of circles as boundaries for the northern constellations. The American **Benjamin Gould** had already introduced such delineations for the southern constellations in 1877. In 1925, the IAU created a subcommittee to settle the matter with Delporte and Casteels among its members. On Delporte's proposal, the subcommittee decided to use only parts of parallels and meridians based on the 1975.0 equinox as boundaries. In fixing the boundaries, the traditional shapes of the constellations were respected as much as possible and reattribution of stars from one constellation to another was reduced to a minimum. The final demarcation was made by Delporte alone in order to obtain a maximum of uniformity in the results.

When Delporte finished this work in 1927, the IAU asked him to also delimit the southern constellations using the same principles. Gould had previously used oblique arcs of circles in his delineation. Delporte replaced these by combinations of parallel and meridian arcs, without changing one star's constellation in Gould's catalog. The whole system of boundaries was published by the IAU in 1936 under the title *Délimination scientifique des constellations* and has been in use unchanged since then.

Tim Trachet

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Dembowski, Ercole [Hercules]

Born **Milan, (Italy), 12 January 1812**
Died **Albizzate, (Lombardy), Italy, 19 January 1881**

Baron Ercole Dembowski observed double stars with unprecedented accuracy, remeasuring almost all stars listed in the Dorpat Catalogue. His instructions and suggestions on how to measure double stars with the micrometer are still considered of great value for the observer.

The son of Giovanni Dembowski, a nobleman of Polish descent and general in the army of the Kingdom of Italy founded by Emperor Napoleon I, Ercole Dembowski was orphaned in 1825 at the age of 13. Dembowski enlisted in the Austrian Imperial Royal Navy, eventually rising to become a commissioned officer. He retired from the navy in 1843 for reasons of health and settled in Naples. In Naples, Dembowski met Antonio Nobile, an astronomer at the Capodimonte Observatory. Encouraged by Nobile, Dembowski purchased a 5-in. refractor with which he started to measure double stars from his observatory in San Giorgio a Cremano, a Naples suburb.

In 1857, Dembowski published his first set of double star measures, a reobservation of stars in the Dorpat Catalogue. Other publications followed in 1860, 1864, and 1866. In 1870, Dembowski moved to Gallarate, between Milan and Varese, in northern Italy, where he made a complete revision of **Friedrich Struve**'s catalog by using an excellent 7-in. Merz refractor. This catalog was published posthumously in 1883 in Rome. In 1879, Dembowski was forced to stop his observing because of frequent gout attacks.

In 1878, the Royal Astronomical Society awarded Dembowski its Gold Medal for his researches on double stars. A crater on the nearside of the Moon was named for him.

Raffaello Braga

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Democritus of Abdera

Born **Abdera (Ávdhira, Greece), *circa* 460 BCE**
Died **(Greece), *circa* 370 BCE**

Democritus's intellectual interests spanned an enormous range, from the mathematical and physical nature of things to the ethical and social sphere.

Tradition holds that Democritus was born in the 80th Olympiad (460–457 BCE) and lived to at least 90 years. Many sources give 460–370 BCE for his life span. It is reported that **Leucippus**, his teacher, was old when Democritus was at his height, and he tells us himself that he was a young man in **Anaxagoras**' old age, being 40 years his junior. Democritus was also a contemporary of Socrates.

Democritus was born into a wealthy family and chose to use his rather substantial inheritance to travel, study, and learn as much as possible. He traveled over much of the known world including Egypt, Persia, Babylon, and possibly even India. Everywhere he went, Democritus sought out men of learning and studied under their direction. According to Diogenes Laertius, as a young man Democritus visited Athens to see Anaxagoras. When Democritus had expended his wealth, he returned to Abdera and started a school, which lasted beyond his lifetime.

Democritus is credited by Diogenes Laertius as having written 73 works (other writers say fewer) on an incredibly wide range of subjects, from the nature of matter (for which he is most famous) to ethics, psychology, mathematics, astronomy, and medicine. It is unfortunate that none of these extensive works survive, and only titles and fragments handed down by others are known. We have some insight into his thought through the fragments of his texts preserved in the writings of later authors, among them Diogenes Laertius, **Theophrastus**, Aëtius, **Plato**, **Aristotle**, **Epicurus**, and **Lucretius**.

Leucippus is often cited as the father of the atomic theory, but it is clear that others, perhaps even the Pythagoreans, conceived of the material world being composed of individual particles. In any case, Democritus developed the atomic theory in a rather complete and consistent fashion, explaining the origin and operation of the world and elaborating Leucippus' more primitive statements. The crux of the atomic theory, as expounded by Democritus, is that the world is made up of "[the] full and the empty," *i. e.*, indivisible particles that are constantly in motion and empty space. Changes in shape and condition, the coming into being of things and their disintegration result from the continual aggregation and tearing apart of the atoms. The atoms themselves do not change; they are indivisible. (The word atom comes from a Greek word meaning "uncuttable.") The atomic theory as propounded by Leucippus and Democritus was a deterministic theory that eliminated the need to introduce the "gods" to explain physical phenomena.

The atomic theory as conceived by these philosophers provides a basis for a self-consistent cosmology, in which the facts of observation played an important role. In many ways, Democritus' astronomy mirrors some features of Anaxagoras' but without much in the way of theoretical innovation. The fact that theory did not improve is surprising, since Democritus appears to have been a rather remarkable mathematician. Diogenes Laertius lists five mathematical texts attributed to Democritus, one on the contact of a circle and a sphere, two on geometry, one on numbers, and one on irrationals.

D. R. Dicks lists a number of titles attributed to Democritus that concern astronomical topics. Among these are writings *On the Planets*, *The Great Year* or the *Astronomy*, and *The Calendar*. The astronomical ideas of Democritus included the notion that there are multiple worlds, of differing size, stage of development, and support of living creatures. Further, he said that the stars are (fiery) stones, and the Sun is a luminous red-hot stone or a stone on fire, and of very great size. The Moon has plains, valleys, and mountains that cast shadows. According to **Plutarch**, he seemed to accept the notion that the Moon is luminous due to reflected light from the Sun. The Earth is disk-like but somewhat hollow or concave, contrary to Anaxagoras's flat disk. Democritus, following **Parmenides**, thought that the Earth was in a state of stationary equilibrium. Many Greeks at the time supposed that the Earth was circular with Delphi at its center, but Democritus, according to Agathemerus, recognized that the Earth was oblong with its length being one and a half times its width. (It is not clear how to reconcile this statement with the previous description of the shape of the Earth.) Democritus, along with **Eudoxus**, is credited with creating a map of the Earth based on geographical and nautical surveys, in the manner of **Anaximander** and Hecataeus of Miletus. He agreed with Anaxagoras that the Milky Way consisted of a multitude of very close stars whose light blurs together to form a rather continuous distribution. Comets were conjunctions of planets or stars that come close together so that their light blurs to form an elongated object. According to Aëtius, Democritus arranged the heavenly bodies, starting from the Earth, in the order Moon, Venus, the Sun, next the other planets, and finally the fixed stars. **Seneca** reported that Democritus held that the planets were at different distances from the Earth and that there might be stars that have motions of their own. **Vitruvius** ascribed a catalog of stars to Democritus, and Censorinus said that Democritus put the Great Year at 82 years with 28 intercalary months. (This, however appears to be an error because 28 intercalary months would correspond to 76 years.) According to **Otto Neugebauer**, Democritus gave the intervals between equinoxes and solstices to be 91, 91, 91, and 92 days, with the last being the number of days between the vernal equinox and the summer solstice, assuming 365 days as the length of the year.

Democritus attempted to demystify natural phenomena, expounding a deterministic rationale for the operation of the world based on a complex system of eternal atoms in constant motion. His works were contested and yet admired by giants of the ancient world such as Aristotle and **Archimedes**. The fact that only fragments of Democritus's many works survive is a great loss to our understanding of the evolution of ancient Greek philosophical thought.

Michael E. Mickelson

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Denning, William Frederick

Born **Redpost, Somerset, England, 25 November 1848**
Died **Bristol, England, 9 June 1931**

Although William Denning received no formal training as a scientist, he was considered to be one of the highest ranking of British Victorian astronomers in his later life. His reputation was built on a lifetime dedicated to the study of meteor showers and the distribution of meteor shower radiants, as well as cometary observations and planetary studies, especially of Jupiter.

Denning was the eldest of four children born to Issac Poyntz and Lydia (*née* Padfield) Denning. Little is known about his early childhood and education. Although he may have trained as an accountant in the Bristol area, there is no indication that it was a full-time vocation. He earned some income by writing popular astronomy articles, and probably received occasional monetary contributions from family and friends before the British Government awarded him a Civil List Pension in 1904 for his services to astronomy and because of his straitened circumstances.

Denning's first significant contribution to meteor astronomy was made in 1877 when he measured the daily radiant drift rate of the Perseid meteor shower. This result had, in fact, been long anticipated, but it was Denning who first performed the required observations and analysis. His study of meteor radiants culminated in the publication of his "General Catalogue of the Radiant points of Meteoric Showers" in 1899. The "General Catalogue" contained information on 4,367 radiants deduced by Denning from approximately 120,000 projected meteor paths. He believed that there were some 50 meteor showers active each night of the year. For the most part, he believed they were very minor showers, delivering just one or two meteors per night, and that some meteor showers had radiant points that were stationary – fixed in their position on the celestial sphere for many months on end.

Although the "General Catalogue" marked the zenith of Denning's career, it also brought him into conflict with other researchers in the field. Many meteor astronomers, notably **Charles Olivier** in the United States, felt that Denning's radiant reduction methods were not exacting enough and that the vast majority of his claimed radiants were illusory and produced by random groupings of sporadic meteors. The stationary radiants were questioned in the sense that their existence could not be explained in terms of cometary associations. **Alexander Herschel**, Denning's strongest supporter on this issue, argued that stationary radiants might be associated with interstellar meteoroid streams, but the problem was never resolved during Denning's lifetime. Denning never wavered in his belief that stationary radiants existed, but more recent astronomy has shown that stationary meteor radiants cannot exist. A more stringent definition of a shower recently adopted by astronomers has also reduced the number of regularly identified meteor showers to about 40 per year.

As an observer of the terrestrial planets, Denning focused his attention on Mercury and Venus, and summarized his work, as well as that of many previous observers, in a small monograph. However, his dominant interest among the planets was clearly Jupiter, for which his many hours of observation were devoted to mapping transient features and timing central-meridian transits [CMT] of Jupiter's Great Red Spot [GRS]. Denning published numerous papers on Jupiter's rotation rate. The American astronomer **George Hough** favored the use of a micrometer for making measurements of Jovian markings, and challenged Denning and his contemporary **Arthur Williams** on the accuracy of their central-meridian transit-timing method. More recent analyses have shown that Denning, Williams, and others were fully justified in using the CMT technique and that it could produce Jovian longitudes that were quite as accurate as Hough's micrometer measurements, although the latter were clearly preferred for Jovian latitude determinations. Using not only his own observations but also those of near contemporaries like **Joseph Baxendell**, **William Dawes**, and **William Huggins**, Denning was able to show that the GRS has a variable rate of motion. Moreover, he found that it was likely that the white hollow recorded by **Samuel Schwabe** was identical to the hollow in which the GRS typically resides. Working through historical data, furthermore, Denning made a convincing case that connected the GRS to phenomena recorded by **Giacomo Maraldi** (1665–1729), and even as far back as **Robert Hooke** (1635–1702).

Denning's seemingly boundless enthusiasm and dedication to observing the heavens is considered the impetus for his discovery of several comets: C/1890 O2; C/1891 F1; the short-period comet 72P/1881 T1 (Denning–Fujikawa), lost until its accidental rediscovery in 1978; and the lost short-period comet D/1894 F1. He is also credited with the discovery of Nova Cygni in 1920 and with the discovery of numerous nebulae.

In his later years, Denning lived a reclusive life and preferred to maintain his extensive scientific contacts by correspondence. However, in the late 19th century Denning belonged to numerous societies and served in several cases as officers of those organizations. He helped found and served as secretary-treasurer of the Observing Astronomical Society during its brief existence as a haven for many of the leading amateur astronomers in the late 1860s. He was elected a fellow of the Royal Meteorological Society (1872) and a fellow of the Royal Astronomical Society (1877). Denning was president of the Liverpool Astronomical Society for their 1887/1888 session. When that organization collapsed, Denning founded and served as director for the British Astronomical Association's Comet Section (1891–1893) and directed the Meteor Section between 1899 and 1900. Denning was elected a corresponding fellow of the Astronomical and Physical Society of Toronto (later the Royal Astronomical Society of Canada) in 1891. From 1922 to his death in 1931, Denning was the first president of the International Astronomical Union's Commission 22 on Meteors.

In addition to the recognition implied by elections noted above, Denning received many awards during his lifetime. Denning received the Valz Prize from the French Academy of Science in 1895, and the Royal Astronomical Society Gold Medal, its highest award, in 1898. The Astronomical Society of the Pacific awarded Denning their Donahue Bronze Comet Medals for his discovery of comets in 1890, 1892, and 1894. The University of Bristol bestowed an honorary master of science degree upon Denning in 1927. Craters on both Moon and Mars have also been named in Denning's honor. Denning never married and had no children.

Martin Beech

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Derham, William

Born **Stoulton, Worcester, England, 26 November 1657**
Died **Upminster, (London), England, 5 April 1735**

William Derham was one of the minor but not insignificant physico–theologians who endeavored to bolster conventional theology by associating it with the scientific interests of the half century or so that followed the founding of the Royal Society in 1660. Educated at Blockley Grammar School and Trinity College, Oxford, he was ordained deacon (1681) and priest the following year. As an Anglican clergyman, he served as Vicar of Upminster for the greater part of his life, a living he took up in August 1689. Derham's first book, *The Artificial Clock-Maker*, was published in 1696. He was later installed as Canon of Windsor in 1716. A friend of **Isaac Newton** and an active fellow of the Royal Society during the latter's presidency, Derham was acquainted with **Edmond Halley**, **John Pound**, **James Bradley**, the naturalist John Ray (whose papers he edited), and others of eminence. He was Boyle Lecturer (1711/1712).

Derham had a passionate interest in the natural sciences, and was a very enthusiastic astronomer. He observed with a large telescope left to the Royal Society by **Christiaan Huygens**. In 1700, Derham began a long series of observations of Jupiter. He also studied the Moon and other planets, being among the first to record the so-called ashen light of Venus. He observed lunar eclipses, and on 20 March 1706 described "a Glade of Light" he saw in the heavens, and yet, again, in April 1707 "a Pyramidal Appearance" in the sky at sunset, as he rode home. His ideas about an inhabited Moon are rationalized in his celebrated *Astro-Theology* (1715), a corollary to the Boyle lectures. This appears to be a continuation of the argument he set out in its companion volume *Physico-Theology* (1713), namely to reason through science to God.

At Upminster, Derham made a special study of the Sun and his results, published in the *Philosophical Transactions,* have been cited in modern investigations of the so called Maunder minimum, that period from about 1645 to 1715 when, so the record suggests, sunspot activity went into unusual decline. In addition, Derham regularly contributed papers to the *Philosophical Transactions*, writing on topics as varied as the migration of birds, botanical observations, the great storm of 1703, the weather, and the barometer. Most of these essays include references to astronomical affairs.

Richard Baum

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Descartes, René

Born **La Haye, (Indre-et-Loire), France, 31 March 1596**
Died **Stockholm, Sweden, 11 February 1650**

Besides his contributions to philosophy (which he completely reshaped), René Descartes produced major results in mathematics (the development of analytic geometry), optics (discovery of the sine law of refraction), and physiology (the discovery of reflex action), and he was a key figure in the development of 17th-century cosmology.

Descartes was the third surviving child of Joachim Descartes and Jeanne Brochard. He was educated at the Jesuit College at La Flèche from 1606 to1614 and studied civil and canon law at the University of Poitiers in 1614–1616. After 2 years in Paris, he joined the army of Prince Maurice of Nassau in 1618, leaving it for that of Maximilian of Bavaria in the following year. By this time he had developed an intense interest in mathematics and optics, and after various travels between 1620 and 1625, Descartes settled in Paris, where he worked primarily in optics. At the end of 1628, he left for the Netherlands, where he was to remain for the next 20 years. Early in 1649, Descartes moved to the court of Queen Christina of Sweden.

In his *Principles of Philosophy* of 1644 (and in his posthumously published manuscript *The World* of 1663), Descartes formulated the first comprehensive physical heliocentric cosmology, that is to say, he provided the first heliocentric system that accounted for the structure of the cosmos in physical terms. The model he set out was one in which the cosmos contains one kind of matter and no empty spaces. Matter, for Descartes, was purely extension. With no voids, any motion implied that matter would be moved and other matter would immediately replace it. Motion could occur only through contact, so that matter must be pushed. This vision of matter, together with a set of dynamical rules that govern collisions of particles, laid the groundwork for the "mechanical philosophy of nature," in contradistinction to the Neoplatonism of **Johannes Kepler**.

When God imparted motion to the Universe at the beginning, extension was broken into three forms of matter: a third element, which made up gross bodies; spherical second element particles that filled the interstices of third element matter and the space between stars and planets; and a finer first element that formed the stars and ensured no voids between particles of the other elements. The initial motion in this material plenum caused many circular displacements resulting eventually in huge vortices, carrying planets about stars. Such a view implied that the Universe must be infinite and that a plurality of worlds was a natural consequence of Descartes's physics. This was a clear break from his contemporaries' thoughts.

Heavier bodies, such as planets, are projected radially outward from the center of the vortices. Descartes treated weight as a function of the amount of matter cohering together and of the internal motion of its parts, and adopted a notion of centrifugal force whereby heavier bodies are projected radially outward from the center as a direct effect of rotation, the heavier the body the greater the force acting on it. However, since this occurs in a plenum, and indeed within a region bounded by several other similar rotating regions, the heavier corpuscles cannot be pushed out indefinitely, but come to reach bands in which the centrifugal forces pushing them onward and the swiftly rotating heavier matter beyond them hold them in stable orbits. Much of the lighter matter is squeezed into the center in the process, and Descartes argued that this lighter matter, because of its very high degree of agitation, is responsible for light and heat. What this means is that these rotating systems have at their centers light, hot matter that, because it rotates, radiates light and heat radially from its surface in all directions. It is what we call a star or a Sun, and each such Sun or star lies at the center of its own Solar System, which takes the form of a vortex.

The next stage after the formation of solar systems is the formation of planets. The surface of the Sun at the center of a vortex can, over time, become occluded by a buildup of less active agglutinated matter and this phenomenon, familiar in our own Solar System in the form of sunspots, can ultimately lead to the Solar System's having insufficient agitation to withstand pressures from contiguous vortices, resulting in the ultimate collapse of that system. When this happens, the occluded star passes into the vortex into which its own has now collapsed, but because it is occluded, it has formed a hard surface around its central core. If the body is massive enough, it will have sufficient force to move from system to system, and it will become a comet. Otherwise, it is captured by the vortex into which it has been introduced as a result of the collapse of its own vortex, and it becomes a planet or, more rarely, a satellite. Planets are carried around by the fluid in which they are embedded, the stability of each planetary orbit being secured by the fact that the planet is only in equilibrium in that orbit and cannot move either away from the center or toward it. If the planet were to move away from the center, it would encounter larger slower particles that would decrease its speed and make it fall back toward the center, whereas if it were to move toward the center it would encounter smaller faster particles that would augment its force and push it from the center. Satellites, which have the same density as the planets they orbit but a greater degree of agitation, are carried around the planet in a mini-vortex, whose physical properties are the same as those of full vortices.

Descartes' interest is in the basic physical principles underlying the structure of the cosmos, and he is not concerned with astronomical detail. He is prepared to allow that planetary orbits might not be perfectly circular, indicating that they might be elliptical because the precise shape of the vortex will be determined by the pressure exerted on it by contiguous vortices, but his concern is not with a true ellipse but rather with a stretched circle that still has only one center. However, Descartes does make some effort to account for discrepancies in planetary speeds.

Other things being equal, in Descartes' system the further from the center of the vortex a body is, the more quickly it moves. However, he knew that Mercury revolves more quickly than Saturn. To save the appearances here he postulates an artificial augmentation of the speed of the globules that fill up the regions between planets and stars in the region between the Sun and Saturn, caused by the rotation of the Sun, which results in those bodies contiguous to its surface rotating more rapidly, accelerating those contiguous to these as well, but to a slightly lesser degree, and so on out to Saturn, where the effect finally peters out.

A second problem is that sunspots move more slowly than any of the planets, which seems to contradict the theory that the Sun rotates so rapidly that it accelerates the fluid surrounding it. Descartes's response to this is to postulate the existence of a solar atmosphere that slows down the spots and extends as far as Mercury.

Descartes abandoned plans to publish *The World* on hearing of the condemnation of **Galileo Galilei** by the Roman Inquisition in 1633, but he reworked his cosmological system in his *Principles of Philosophy*, and extended the vortex theory–which already covered the production and transmission of light, the formation and collapse of solar systems, the formation of planets and their satellites, the stability of planetary orbits, the tides, and the behavior of comets–to provide an account of gravity, magnetism, and (very briefly) static electricity. The aim of the vortex theory at the most general level was to account for all these phenomena purely in terms of contact forces, and its success in this respect appealed to generations of natural philosophers, from his immediate followers such as **Jacques Rohault** and **Pierre Régis,** up to **Johann Bernoulli**, **Leonhard Euler**, and **Bernard de Fontenelle**. **Isaac Newton** went to a great deal of trouble in the *Principia*, principally in Book II, to refute the idea that planetary orbits can be accounted for in terms of planets being carried around in fluids, arguing in detail that fluids offered resistance to the motion of bodies.

Stephen Gaukroger

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Deslandres, Henri-Alexandre

Born **Paris, France, 24 July 1853**
Died **Paris, France, 15 January 1948**

French solar astronomer Henri Deslandres carried out intensive studies of the behavior of the various layers of the atmosphere of the Sun – photosphere, chromosphere, and corona – and their changes through the solar cycle. He graduated from the École Polytechnique in Paris in 1874 and began a career in the army, rising to the rank of captain in the engineers, but resigned in 1881 to begin research in ultraviolet spectroscopy with **Alfred Cornu** at the École Polytechnique. Later at the Sorbonne, Paris, he received his doctorate in 1888, for work on arithmetic laws that describe the wavelengths of various bands in molecular spectra (Delandres's third law).

Like many French physical scientists of the 19th century, Deslandres had a strong interest in physical and instrumental optics, and their application to a variety of fields, including astronomy, meteorology, astrophysics, and spectroscopy. He was appointed to the Paris Observatory in 1889 and put in charge of setting up a spectroscopic department there by director Admiral **Ernest Mouchez**. In 1897, Deslandres was appointed assistant astronomer at the Meudon Observatory, an observatory created by **Jules Janssen** in 1876 specifically for astrophysical work. There, Deslandres rapidly rose through the ranks, becoming astronomer in 1898, assistant director in 1906, and (upon Janssen's death), in 1908, director of the Meudon Observatory. When the Paris and Meudon observatories were united in 1926, he also directed the new institution until his retirement in 1929.

Deslandres and his contemporary **George Hale** represent the second generation of solar physicists. From the 1880s, both men (often in competition with each other) furthered the knowledge of the constitution and circulation of the solar atmosphere, notably through their introduction of photography to record the appearance of prominences, and their nearly simultaneous invention in 1894 of a new instrument, the spectroheliograph, with which the spectra of selected parts of the solar atmosphere could be photographed and studied, giving clues about their composition. Always an experimentalist and an instrument-designer rather than a theorist, Deslandres later created another device, the *spectro-enregistreur des vitesses*, to monitor the radial velocities of solar gas clouds using the Doppler effect. From extensive investigations with increasingly sophisticated versions of these two instruments, Deslandres was able to conclude that the chromosphere does not vary much during the sunspot cycle, whereas the areas associated with faculae display variations similar to those shown by the faculae during this cycle. He also showed that plages (a term he coined) have the same structure as prominences. Convinced of the magnetic nature of solar spots, Deslandres further carried out, with the assistance of **Louis d'Azambuja**, an ambitious program of daily photographing of the Sun.

Deslandres employed his spectrographic devices for measuring stellar radial velocities, and the rotational velocity of Jupiter and Uranus as well as of Saturn and its ring, showing that Uranus was retrograde. He also looked into the spectra of comets and their tails. Deslandres further participated in several eclipse expeditions: to Fundium, Senegal, in 1893; to Japan in 1896; and to Spain in 1900 and 1905. His spectra of Arcturus and Aldebaran provided the earliest evidence for the existence of chromospheres in red giants.

Deslandres played a major role in international astronomical organizations, representing the Société Astronomique de France at the 1904 conference where the International Union for Co-operation in Solar Research was founded, and serving on its committees on solar research with the spectroheliograph to investigate the spectra of sunspots and solar rotation. He was the delegate of the French Academy of Sciences to the 1919 meeting in Brussels, where both the International Research Council (now [ICSU]) and the International Astronomical Union [IAU] were established, and served as vice president of the IAU from 1922 to 1928. The French Academy of Sciences elected Deslandres to membership in 1902 and to its presidency in 1920, and the corresponding academies in Belgium, Italy, the United Kingdom, and the United States elected him in later years. He received medals from the United States National Academy of Science, the Royal Astronomical Society, and the Astronomical Society of the Pacific. The French Académie des sciences named a prize for Deslandres shortly after his death. He and his wife had one son, Philippe.

Charlotte Bigg

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Deutsch, Armin Joseph

Born **Chicago, Illinois, USA, 25 January 1918**
Died **Pasadena, California, USA, 11 November 1969**

American spectroscopist Armin Deutsch focused on the analysis of the hot (type A) stars, particularly those with strong magnetic fields, with patchy distributions of heavy elements like europium on their surfaces. Deutsch received his BS from the University of Arizona (1940) and his Ph.D. from the University of Chicago (1946) for work at Yerkes Observatory on the spectra of A-type variable stars. His graduate career was interrupted by service as an instructor at a technical training school of the United States Army Air Force at Chanute Field, Illinois (1942–1944). He held positions as assistant astronomer at Yerkes Observatory (1944–1946), instructor at Ohio State University (1946/1947), and instructor (1947–1949) and lecturer (1949/50) at Harvard University, before joining the staff of Mount Wilson and Palomar Observatory in Pasadena in 1951, where he remained until his death.

Beginning at Yerkes and continuing at Mount Wilson and Palomar, Deutsch gradually established that the variations in brightness, absorption line profiles, Zeeman broadening, and surface abundances of the chemical elements of a subset of the A stars, called Ap (for peculiar), could all be explained by an "oblique rotator model," originally put forward by **Horace Babcock** and Douglas W. N. Stibbs. The idea was that the north–south axis of a strong magnetic field was not parallel to the rotation axis, so that, through the rotation period (typically a day or two), we see both different field strengths and parts of the surface in which different chemical elements have been concentrated. Particularly important was an analysis of the star α^2 Canum Venaticorum, carried out with **Jesse Greenstein** and their student Judith Cohen (now professor of astronomy at the California Institute of Technology).

Toward the end of his life, Deutsch addressed several other problems in hot stars and stellar rotation, particularly the so called blue stragglers (stars whose temperatures and brightnesses make them look younger than the clusters in which they are found). He recognized that many of these are rapid rotators, and suggested that, even though their surfaces slowed down, many stars (including the Sun) might maintain rapidly rotating cores, which could be revealed again later. This connected directly with the gravitation theory of **Robert Dicke** and Carl Brans, which required the inside of the Sun to rotate rapidly. The correct explanation for straggler rotation is probably that they are merged binary-star pairs.

Deutsch also wrote scientifically-based science fiction, some of which was anthologized in his lifetime.

Léo Houziaux

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Dick, Thomas

Born **Dundee, Scotland, 24 November 1774**
Died **Broughty Ferry, (Tayside), Scotland, 29 July 1857**

Thomas Dick was the son of Mungo Dick, a Scottish linen weaver, and is best known for his reconciliations of science with religion. When about eight years old, young Thomas witnessed a brilliant meteor and thereafter studied astronomy in earnest. The boy reluctantly tried to follow in his father's profession but reportedly studied books even while working at his loom. He fashioned one or more crude telescopes from discarded spectacle lenses that he reground and polished himself. At the age of sixteen, Dick left his family to pursue his own vocation. For four years, he served as an assistant teacher in Dundee.

In 1794, Dick enrolled at the University of Edinburgh and supported himself by private tutoring. He studied chiefly philosophy and theology. After completing his studies *circa* 1800, Dick was licensed to preach under the auspices of the Secession Church and became an itinerant pastor. He returned to teaching at the Secession school at Methven, *circa* 1807. His educational reforms sought an increased role for science and fostered the principles of object teaching. Dick supported the abolition of slavery and the education of women. He founded a public library and a precursor of the later-named mechanics institutes. In 1817, Dick transferred to a school at Perth, where he spent another decade as schoolmaster.

It was at Perth that Dick composed his first significant work, *The Christian Philosopher* (1823), which established his subsequent literary career. Dick's writings embraced the tenets of natural theology, by which the existence, benevolence, and wisdom of the Creator were to be inferred from an inspection of His works, especially the heavens. These included his *Philosophy of Religion* (1825), *Celestial Scenery* (1838), *The Sidereal Heavens* (1840), and *The Practical Astronomer* (1845).

In 1827, Dick gave up his teaching post and built a cottage at Broughty Ferry. It contained a tower observatory and three telescopes. Dubbed Herschel House, after astronomer **William Herschel**, this was Dick's final dwelling place and the source of his greatest literary output. His works were widely read and acclaimed on both sides of the Atlantic. Dick became a popular lecturer. In 1832, he was awarded an honorary L.L.D. by Union College of Schenectady, New York, USA. Dick was thrice married and had numerous dependents. Although his books sold well, he received little financial return from his writings. In his later years, Dick was supported by a pension from his friends, and by another from Queen Victoria after 1855.

Dick was a strong proponent of the "plurality of worlds," *i. e.*, a belief in the widespread existence of extraterrestrial life. He readily imagined races of beings residing not only among the Solar System's planets but upon comets and around nearly every star in the sky. Dick, however, seems to have dodged more complex theological issues concerning the spiritualities of his purported aliens. His writings were infused with a cosmic mysticism that was nonetheless based on a firm grasp of astronomical principles.

Dick's influence proved to be long-lasting. In 1935, Scottish industrialist John Mills established a public observatory at Dick's birthplace of Dundee. For over two generations, the Mills Observatory has brought astronomy to visitors of all ages, exactly as Thomas Dick might have wished.

Jordan D. Marché, II

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Dicke, Robert Henry

Born **Saint Louis, Missouri, USA, 6 May 1916**
Died **Princeton, New Jersey, USA, 4 March 1997**

American experimental physicist Robert Dicke invented the microwave radiometer and lock-in amplifier that bear his name and that made possible the discovery of the cosmic microwave background radiation; he also carried out a number of experiments clarifying the properties of gravitation on terrestrial and astronomical scales.

Dicke was the son of a patent attorney. He grew up in Rochester, New York, where he began undergraduate studies at the University of Rochester, and got a transfer to Princeton University (where he published his first paper, modeling globular clusters as a gas of stars) to complete his bachelor's degree in 1939. Dicke received a Ph.D. from the University of Rochester in 1941, for the work with Lee DuBridge in nuclear physics, and held honorary degrees from Edinburgh University, Rochester, Ohio, "Northern University," and Princeton University.

Immediately upon receipt of his doctorate, Dicke joined the Radiation Laboratory (Rad Lab) at the Massachusetts Institute of Technology, working on radar. He invented the microwave radiometer (often called a Dicke radiometer) in order to measure atmospheric absorption of centimeter radio wavelengths. This absorption set limits to pushing radar toward shorter wavelengths for better angular resolution. Dicke also applied it to make the first measurement of thermal emission from the Moon in that band and to set a limit of 20 K to radiation from "cosmic matter" at 1–1.5 cm. His invention of the lock-in amplifier, or Dicke switch, also dates from the Rad Lab period. These were the key technologies that later made possible the discovery of the cosmic relic radiation.

Returning to Princeton University in 1946 as assistant professor of physics, Dicke focused first on quantum aspects of the interaction between matter and radiation. His method of suppressing the Doppler broadening of spectral features is called Dicke narrowing and is important in atomic clocks and in the operation of the Global Positioning System. He recognized that lasers are best constructed with a pair of mirrors at the ends of an open tube (rather than with a closed cavity as for masers). His method of extracting more than thermal radiation from an inverted population of atomic levels is called Dicke superradiance. Dicke became the Cyrus Fogg Brackett Professor in 1957 and was named the first Albert Einstein University Professor of Science in 1975 (and Einstein Professor Emeritus from 1984 to his death). Among his students at Princeton University who have made important contributions to physics and astronomy are Robert Romer (past editor of the *American Journal of Physics*), James Wittke (coauthor with Dicke of a much-used textbook in quantum mechanics), Kenneth Libbrecht (who studies solar oscillations), and Jeffrey Kuhn.

From 1955 onward, Dicke's interests turned gradually toward gravitation, astrophysics, and cosmology. Between 1956 and 1964, he set the tightest limit ever on possible violations of the principle of equivalence of gravitational and inertial mass (the Dicke–Eötvös experiment, named for him and his predecessor Lorand Eötvös). Dicke became increasingly concerned that general relativity [GR] did not explicitly include the ideas about the interaction between local gravity and the Universe as a whole, generally associated with the name of Ernst Mach. With Carl Brans, Dicke put forward a more complex theory of gravity that included both tensor (like GR) and scalar parts. Dicke realized that, within this scalar–tensor picture of gravity, the observed advance of the perihelion of Mercury would not be fully accounted for, and he suggested that the Sun might have a rapidly rotating core and a distorted shape that would account for the rest. There were, at the time, other astronomical reasons to favor interior rapid rotation. Dicke and several students developed a solar telescope to look for the distorted shape, and in the 1970s, it seemed as if they had found it. In fact, they had been fooled by observing near solar maximum, when there was a good deal of excess brightness near the solar equator due to the plages and faculae of active regions, as became clear when his former student, Henry Hill, repeated the observations from Arizona at solar minimum. Dicke, Libbrecht, and others eventually set a tight limit to real solar oblateness, which has since been confirmed by the solar oscillation studies. The scalar–tensor theory then went out of favor, but modern string theories of gravity are of the same general form.

Also, in about 1961, Dicke began to take a renewed interest in cosmology and to wonder whether one might detect radiation left from the stars of a previous cycle of an oscillating Universe that had been thermalized into microwaves during a "big crunch." He and his associates James Peebles, Peter Roll, and David Wilkinson had just begun the search when it became clear that Arno Penzias and Robert Wilson, at Bell Telephone Laboratories, had accidentally found this leftover cosmic microwave background radiation while measuring the average brightness of the sky for purposes of satellite radio communication. The papers from the two groups were published together, but it was Penzias and Wilson who received the 1978 Nobel Prize in Physics for the discovery.

Another of Diche's contributions that have had long-term implications include the 1961 cofounding of Princeton Applied Research to develop and market the lock-in amplifiers, a prototype for university–commercial relationships, and discussions of why we should find ourselves in a Universe whose density is very close to the critical one needed to reverse the expansion. He made the point that it is essential for our existence as observers that the Universe should have an age (set by gravity) comparable with the lifetimes of stars (set by nuclear reactions and other independent parts of physics). This is now thought of as part of the cosmological anthropic principle.

Dicke was a member of the United States National Academy of Science, receiving the Comstock Medal in 1973. He also received the United States Medal of Science, and awards from the National Aeronautics and Space Administration [NASA], the Franklin Institute, the Microwave Theory and Techniques Society, and the American Astronomical Society (the Beatrice M. Tinsley Award in 1992; the last one he was able to accept personally). In addition to his wartime work at the Rad Lab, Dicke also served the wider community on advisory panels to the National Science Foundation, the National Bureau of Standards, NASA, and the Fulbright Foundation and was a member of the National Science Board (1970–1976). He was a long-term member of the Lunar Laser Ranging team, using the corner reflectors emplaced by the Apollo astronauts to demonstrate that the evolution of the Earth–Moon system agrees with the predictions of gravitation theory. He married Annie Currie in 1942, and they had three children.

Douglas Scott

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Digges, Leonard

Born **near Canterbury, Kent, England, 1520s**
Died ***circa* 1563**

Information about Leonard Digges is a little confused because, of his four major works, three were augmented and corrected by his son, **Thomas Digges**.

Leonard Digges was from a well-established Kentish family, and one would perhaps use the term "gentleman" in describing his occupation. He was educated in mathematics at University College, Oxford, and admitted to the Law school Lincoln's Inn in 1537. Digges was apparently an Anglican and took part in Wyatt's rebellion led by Sir Thomas Wyatt against England's Catholic Queen Mary. As a result of this, Wyatt was executed, but Digges, who received a death sentence for high treason (in 1554), was reprieved but lost his estates after his father's death.

Of Leonard Digges's four works, *Tectonicon* (which was published by Leonard in 1556) was essentially a surveying manual, and *Stratioticos* (which appeared in 1579, being finished and enlarged by Thomas) was a book on mathematics for soldiers. *Pantometria*, which was also concerned with surveying and contains a detailed section on geometry, is interesting for its work on the theodolite (which Leonard Digges is credited with inventing). It appeared in 1571 after being completed by Thomas. Of more significance for astronomy was the book *Prognostication*, published in 1555 by Leonard, and added to later editions by Thomas. This book deals with many topics, including the judgment of the weather from astronomical observations (*e.g.*, the color of the Sun and Moon, the brightness of the stars, and the position of the planets with respect to the zodiacal constellations) and the linking of earthquakes, wars, and changes of government with comets. It also discusses the determining of the time of day through observation of the Sun, Moon, and planets; discusses eclipses of the Sun and Moon; and presents tables for tide movements, sunrise, sunset, and hours of daylight. Although the book was written nearly 500 years ago, and must be judged accordingly, it is in many places what would today be called "astrological." However, it must not be forgotten that much science, even long after Digges' day, suffered from this. The book can be found in reprinted form as *Old Ashmolean Reprint lll* (1926). In his later additions to this book, Thomas Digges took the advantage to state his case for **Nicolaus Copernicus**' solar system.

Graham Hall

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Digges, Thomas

Born **Kent, England, *circa* 1546**
Died **London, England, 24 August 1595**

Thomas Digges's reputation among historians rests largely on the fact that he was the leader of the English Copernicans. Among astronomers, he is remembered as among the first to advocate an infinite stellar universe far outside the orbit of Saturn, populated by stars that might themselves have planets.

Thomas was the son of **Leonard Digges** and Bridget Wilford. He received his mathematical training from his father, who died while

Thomas was in his early teens, and from **John Dee**, who described Thomas as his most worthy mathematical heir. Digges and his wife Agnes Saint Leger had six children, including Sir Dudley Digges and Leonard Digges the younger.

There is no record that Thomas attended any university; his proficiency in mathematical and military matters derived from his father's and Dee's tutoring. He served the government in various capacities. Digges was one of the officers designated in 1582 to repair the harbor at Dover, on which he was engaged for several years; he also served as a member of Parliament in 1572 and 1584/1585, and as a general of the English forces in the Netherlands from 1586 to 1594. He was buried in the church of Saint Mary, Aldermanbury.

Thomas Digges added a discussion of the Platonic solids and five of the Archimedean solids to his father's *Pantometria* (1571) and completed his father's *Stratioticos* (1579). The second editions of both works provided answers to questions on ballistics that had been raised in the first edition of *Stratioticos*.

Digges' reputation among his contemporaries rested on his observations of the new star of 1572, on his ability to cultivate mathematics, and on the preservation of his father's writings and instruments. In *Alae seu Scalae Mathematicae* (1573), he published his observations of the star of 1572, which are regarded as the best published observations next to those of **Tycho Brahe**. Brahe's high opinion of them is attested by his devotion of over 30 pages of his *Progymnasmata* (Prague, 1602) to Digges's treatise.

Digges' father is regarded as the maker of the first efficient telescopes, and Thomas was keen to enhance his father's reputation as much as possible. Among the drawings and descriptions of instruments preserved by Digges are a drawing of a rectilinear scale with transversals and an illustration of the use of a theodolite for estimating the range of artillery rapidly and accurately. In the *Stratioticos*, he added a description of what appears to be a reflecting telescope – 35 years before **Galileo Galilei** and a full 100 years before **Isaac Newton**'s reflecting telescope. Unfortunately, the instrument, if it was ever actually built, is no longer extant, and even the uses for it that Digges attributed to his father in the preface to *Pantometria* do not include any celestial observations.

Already in the *Alae* (1573), Digges referred to the probable truth of the Copernican theory. In 1576, he added an English translation of parts of Book I of **Nicolaus Copernicus**'s *De revolutionibus* to his father's *Prognostication everlastinge* (1576). The full title is *A Perfit Description of the Caelestiall Orbes according to the most aunciente doctrine of the Phythagoreans, latelye revived by Copernicus and by Geometricall Demonstrations approved*. Digges contributed to a misunderstanding that referred to Copernicus as having revived Pythagorean doctrines, but he also altered the Copernican theory in a way that removed Copernicus's ambiguity about the size of the Universe. Copernicus imagined a finite Universe with the stars located in the last sphere and the Sun at the center, but because of Copernicus' uncertainty about the nature of space beyond the stars, he left the question whether it is finite or infinite to natural philosophers. It was Digges who first represented the stars in the Copernican system at various distances, thus committing the theory to an infinite space. By proposing that the stars are at varying distances, however, he was also trying to spur astronomers into making more observations in the hope that they would prove the Copernican theory true or in need of modification. However, he still retained the Sun at the center, indicating that he did not go as far as **Giordano Bruno** in his conception of an infinite universe. The English thus owe their understanding of the Copernican universe as infinite to Digges, who let his own interpretation pass as part of Copernicus's own theory.

The fact that Digges did not carry out telescopic observations may be explained by the circumstances of his career and the fact that he never had the funds to carry out a systematic program of research. On the other hand, he may also have realized that with the instruments available stellar parallax could still not be observed and so did not serve as a crucial experiment of the heliocentric theory. Digges suggested further that the decline in brilliance of the new star of 1572 might be the result of the Earth's motion in its orbit away from the star. If that were true, then after it reached its maximum elongation, the star would begin to increase in brilliance, thus confirming the Earth's orbital motion. In fact, the star continued to fade from view. The hope that a large collection of new and more accurate observations would quickly verify or correct the Copernican theory was too optimistic.

André Goddu

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Dinakara

Flourished **(Gujarat, India), 1578–1583**

The Indian astronomer Dinakara composed three sets of astronomical tables. He belonged to the Moḍha clan of the Kauśika lineage, and was the son of Rāmeśvara and great grandson of Dunda. Dinakara resided in Bārejya (or Bāreja) in Gujarat. His tables are (1) the *Candrārkī* (epoch 1578) for which there is an anonymous commentary on it, (2) the *Khe'ṭasiddhi* (epoch 1578); and (3) the *Tithisāraṇī* (or *Dinakarasāraṇī*) (epoch 1583). The first two tables are planetary tables for computing the longitudes of the planets; the first deals with the Sun and Moon, including the tables for calendar making, and the second with the other five planets. The third is for making Indian calendars. These use the parameters of the Brahma school.

Setsuro Ikeyama

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Dingle, Herbert

Born **London, England, 2 August 1890**
Died **Hull, England, 4 September 1978**

A professional astronomer, Herbert Dingle retrained himself as a historian at the University of London during the early evolution of the history of science as a profession. Spectroscopy, astrophysics, relativity, and cosmology were his main interests as an astronomer. He served a number of years as a Royal Astronomical Society [RAS] council member, secretary, and finally as RAS president from 1951 to 1953. His presidential address in 1953 was a satirical attack on the notion of a "perfect cosmological principle (the underlying idea of the steady-state cosmological model of Herman Bondi, Thomas, Gold, and **Fred Hoyle**, that the Universe should look the same to observers at all times as well as in all places)." In 1956, Dingle triggered a substantial debate with **William McCrea**, soon joined by others, on the Twin or Clock paradox in **Albert Einstein**'s discussion of special relativity. Dingle never accepted the reality of this aspect of special relativity.

Thomas R. Williams

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Diogenes of Apollonia

Flourished ***circa* 430 BCE**

Diogenes believed that the air was the fundamental substance from which all others are formed, and that it also represented the "guiding principle" of the Universe. The similarity between his and **Anaximenes**'s views has caused some to suggest that he was the latter's pupil; this seems unlikely given their probable dates.

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Dionis du Séjour, Achille-Pierre

Born **Paris, France, 11 January 1734**
Died **Vernou near Fortainebleau, France, 22 August 1794**

French mathematician–statesman Achille-Pierre Dionis du Séjour calculated that despite contemporary fears to the contrary the odds of a comet striking the Earth are very low.

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Dionysius Exiguus

Born **Scythia Minor (Dobrudscha, Romania), mid to late 5th century**
Died **possibly Rome, (Italy), before 556**

Dionysius, a monk of Scythian (or Gothic) birth educated in the ecclesiastical tradition on the west coast of the Black Sea, came to Rome sometime after 496, perhaps having earlier resided in Constantinople. Self-styled Exiguus ("the Slight") out of intellectual humility, he was nevertheless an important figure in the canon law, theology, and computistics of Late Antiquity. Skilled in both Latin and Greek, Dionysius was instrumental in the translation of numerous Greek texts into Latin, including documents from the Church councils of Nicaea (325) and Chalcedon (451), along with a wide variety of theological treatises and ecclesiastical records. He was highly regarded by his contemporaries, especially by his friend **Cassiodorus**.

Despite his monumental work in the ecclesiastical sphere, Dionysius is best remembered for his reworking of the Christian calendar. Petitioned by many contemporary clerics in the Church hierarchy, in 525 he undertook the calculations needed to extend for another 95 years the Easter table of Cyril of Alexandria, which spanned the years 437–531. In doing so Dionysius cited the Council of Nicaea's authority in establishing a 19-year luni-solar cycle as the basis for determining the date of Easter and thus guaranteed in the West the acceptance of the Alexandrian method of reckoning the feast date. His work also drew upon and refined the earlier Easter calculations by Victorius, Bishop of Aquitaine, who had established the Paschal Cycle of 532 years (published in 465). Dionysius's table itself was a modified version of Cyril's original, and comprised eight columns, in several of which there was specified lunar and calendrical information, expressed in the Roman manner of Kalends, Nones, and Ides. The actual date of the Easter feast was put in the far right column. In addition, nine arithmetical *argumenta,* or shortcuts for calculation, were appended to the table, as was a letter to an otherwise unknown bishop Petronius explaining the tables and their calculations.

As part of these chronological recalculations, Dionysius also initiated a new method of counting the years. Since the earlier Cyrillan cycle had used the imperial Roman yearly dating system starting in 284 (the ascension of the Emperor Diocletian, a notorious persecutor of Christians), Dionysius abandoned it and started numbering years with the birth of Christ. Thus, he introduced the phrase *Anno Domini* ("In the year of the Lord"), which was incorporated into the Easter table. Yet while the table itself was effective in extending the Cyrillan Cycle, the new system of dating was not perfect. Lacking the concept of 0, Dionysius began the system with the year 1, making the first year of his table 532. Moreover, Dionysius had relied for the date of the Incarnation on Clement of Alexandria, who stated that it occurred in the 28th year of the reign of Augustus. But Dionysius mistakenly assumed that Augustus had counted his regnal years from his official assumption of power in 27 BCE. In fact, they were counted from the battle of Actium in 31 BCE. Uncertainty about the founding date of Rome, which served as the dating system in early imperial times, may also have been a source of some confusion. As a result, Dionysius's entire dating system was inaccurate by 4 years.

Dionysius's new dating system was not readily adopted. Although Cassiodorus used it in 562 for the *Computus paschalis*, and **Isidore** knew of it (*Etymologiae* 6.17), it gained support only slowly. Its wider acceptance began when the British cleric and historian **Bede** incorporated it into his own works, *De temporibus* (On Times, 703), and *De temporum ratione* (On the rechoning of times, 725). Gradually, and because of the authority of Bede in later centuries, Dionysius's system of dating spread throughout Europe.

John M. McMahon

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Dirac, Paul Adrien Maurice

Born **Bristol, England, 8 August 1902**
Died **Tallahassee, Florida, USA, 20 October 1984**

British theoretical physicist Paul Dirac is known within astronomy primarily for the hypothesis that certain ratios of fundamental constants (called "large numbers" because some of them are on the order of 10^{40}) should not change as the Universe expands. Raised in Bristol by an English mother and Swiss father, Dirac was recognized as being bright at an early age. He obtained an engineering degree in 1921 and a mathematics degree in 1923, both from Bristol, then moved to Cambridge to pursue research. Dirac was awarded a Ph.D. in 1926 for work on quantum mechanics with 11 papers already published. He produced the Dirac equation in 1928 and his text *The Principles of Quantum Mechanics* in 1930. He was made Lucasian Professor of Mathematics at Cambridge University in 1932, and remained in that position until 1969, when he moved to Florida State University. Dirac received the Nobel Prize in Physics in 1933 for correctly predicting the existence of the positron.

One of Dirac's earliest papers was on Compton scattering in stellar atmospheres, in 1925. Of course his major work was on unifying quantum mechanics with relativity theory, which led to the notion of antiparticles. But he also made many other theoretical contributions, the most relevant to astrophysics being his 1938 paper presenting a model based on a set of coincidences between atomic and cosmic physics. Although the model itself was quite speculative, and was ultimately ruled out by constraints on the variation of the gravitational constant, it was a remarkably inspirational hypothesis, which continues to have relevance for some of the cosmological theories of today.

Dirac appears not to have interacted easily with students. The best known of them was **Fred Hoyle**, who, however, did not take a formal Ph.D. degree.

In addition to receiving the Nobel Prize, Dirac received honors from the Royal Society of London, the USSR Academy of Sciences, and the United States National Academy of Sciences. His style of nonscientific conversation was uniquely terse and gave rise to a large number of "Dirac stories" (many of them verifiable), of which the punch line was invariably Dirac uttering one or two words in a context where others would have gone on for paragraphs.

Douglas Scott

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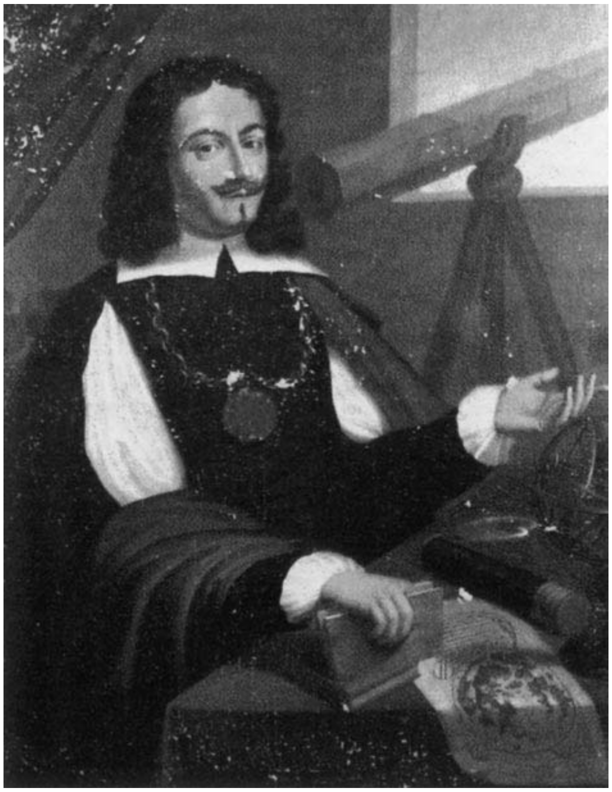
Divini, Eustachio

Born **San Severino, (Marche, Italy), 4 October 1610**
Died **San Severino, (Marche, Italy), 22 February 1685**



Eustachio Divini was one of the leading telescope-makers of the 17th century. Divini's mother, Virginia Saracini, died when he was four, and his father, Tardozzo Divini, died when he was 11. Eustachio was brought up by his elder brothers, Vincenzo and Cipriano, who started him off on a military career. After abandoning the army, Divini went to Rome where he began attending **Benedetto Castelli**'s lessons in mathematics at the university La Sapienza. Here he met many scholars who would become famous scientists, such as **Evangelista Torricelli**, **Giovanni Borelli**, and **Bonaventura Cavalieri**, and he would develop his passion for astronomy and optics.

In the early 1640s, Divini established himself in Rome as a clockmaker. In 1646, he began making lenses and constructing compound microscopes and long-focus telescopes. Many of his instruments have survived in museums in Florence, Rome, Padua, and elsewhere. Between 1662 and 1664, Divini's lenses and instruments competed with those of **Giuseppe Campani**, and a bitter rivalry between the two developed into a feud that involved Pope Alexander VII. Divini was still in Rome in 1674 but soon moved back to his native town, where he spent his last years comfortably, thanks to his wealth.

Divini was among the first to develop technology for the production of scientifically designed optical instruments – he produced long-focus telescopes, some as long as 72 Roman spans (about 16 m), and he was probably the first to use a reticule for the telescope, an important step toward the micrometer. By the 1650s, his telescopes were well known all over Europe – A Divini telescope was used by **Antonio de Reitha**. Sir Kenelm Digby took six of them, one of which he probably gave to **Pierre Gassendi** in 1653. Many Divini instruments were bought by high prelates of the Roman curia.

In 1649, Divini published a copper engraved map of the Moon as a separate broadsheet dedicated to the Grand Duke of Tuscany Ferdinand II, primarily to advertise the quality of his lenses. There are many similarities between Divini's map and that of **Johannes Hevel** (made in 1647). It is evident that Divini had one eye at the telescope and the other on the work of his predecessor. However, there are also enough differences to indicate that Divini did make many observations on his own. In the broadsheet published in 1649, around the big picture of the Moon, there are a crescent, a Saturn with its "handle" (as it was observed between 1646 and 1648), a horned (*cornigera*) Venus, and two pictures of Jupiter with the four Galilean satellites. Divini's map was then twice included in printed books – first in **Athanasius Kircher**'s *Mundus subterraneus* (1665) and subsequently in **Otto von Guericke**'s *Experimenta nova* (1672).

In 1659, **Christiaan Huygens** published his *Systema Saturnium*, in which he a sserted that there was a ring around Saturn. He affirmed, among other things, that his own telescopes were the best and underlined that he saw Saturn much better than Eustachio Divini did. Divini's answer came with a pamphlet (*Brevis annotatio in Systema Saturnium Christiani Eugenii*, July 1660), probably not written by Divini himself but most likely by **Honoré Fabri**, a Jesuit astronomer in Rome. This short treatise spoke ill of Huygens's telescopes, described his ring theory as fantastic, and argued in favor of the theory that Saturn was accompanied by four satellites. After Huygens's rejoinder (*Brevis assertio Systematis Saturnii Sui*, September 1660) and a second Divini–Fabri pamphlet (*Pro sua annotatione in Systema Saturnium Christiani Eugenii adversus eiusdem assertionem*, 1661), the prestigious Accademia del Cimento in Italy performed a series of experiments with models and found that Saturn's appearance was explained most satisfactorily with Huygens's ring theory, but the question was not definitively solved.

From 1662 to 1665, there was another quarrel between Divini and Campani. Both worked in Rome, so some rivalry between them was inevitable. In those years, however, the rivalry became a hot dispute. Many "comparisons" were made between the instruments of these rivals, which Divini mentioned in his letter to Count Antonio Manzini (1666). The first public comparison took place at the end of October 1663 in the garden of Mattia de' Medici, in the presence of some famous astronomers like **Giovanni Cassini**. The contest ended in a draw since they acknowledged that Campani's telescope had better focusing but Divini's had bigger magnification. Many other comparisons were made in the following months, but they virtually ended in July 1665, when Campani's 50-span-long telescope was unanimously judged as the best ever constructed. Even after the bad end of the quarrel with Campani, Divini's instruments continued to be appreciated and esteemed, so he did not stop his work.

Marco Murara

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Dixon, Jeremiah

Born **Bishop Auckland, Durham, England, 27 July 1733**
Died **Cockfield, Durham, England, 22 January 1779**

Jeremiah Dixon was a surveyor and astronomer who, with **Charles Mason**, surveyed the Mason–Dixon Line delineating the boundary between Maryland and Pennsylvania, USA. Dixon was born to well-to-do Quaker parents, George and Mary Hunter Dixon; his father owed a coal mine that was believed to have drawn coal as far back as the 14th century. Dixon was educated in private schools, where he excelled in mathematics and astronomy.

With the transit of Venus of 1761 impending, Astronomer Royal **James Bradley** chose Mason to lead an observatory expedition to Bencoolen, Sumatra. On the voyage, he was accompanied by Dixon. They departed in November 1760 aboard *HMS Seahorse* with orders to proceed to Bencoolen unless it was in the hands of the French, in which case they would divert to Batavia. While still in the English Channel, the *Seahorse* was attacked by the French frigate *Le Grand*. After a violent battle, which lasted barely an hour, the captain was able to return the ship back to Plymouth. However, upon witnessing the casualties and damage to both the ships and some of the astronomical equipment, Mason and Dixon wrote of their desire not to go to Bencoolen. Instead, Mason suggested the eastern portion of the Black Sea, where they would be able to observe first contact, but not the planet leaving the face of the Sun.

The Royal Society not only denied their request but also threatened them with a lawsuit, so the voyage to Bencoolen was recommenced. However, by the time they were rounding the Cape of Good Hope, they received news that Bencoolen had been taken by the French. Arriving at the Cape in April 1761, Mason and Dixon prepared to observe the transit from there. As luck would have it, their observations at the Cape of Good Hope were the only successful ones for the South Atlantic region – others were clouded out.

Afterward, Mason and Dixon joined **Nevil Maskelyne** on the island of Saint Helena, assisting him in various measurements such as tides, longitude, and the gravitational constant.

In 1763, as a result of the successful collaboration with respect to the transit of Venus, Mason and Dixon were charged with the responsibility of surveying what is still referred to as the Mason–Dixon Line. The language of the original land grants to William Penn (later the state of Pennsylvania) and to Lord Baltimore (later Maryland) were sufficiently vague that by the mid-18th century the argument between their respective heirs required the appointment of a commission in 1760 to adjudicate the border dispute. Three years later, Mason and Dixon were hired to survey and establish the boundary. Arriving in America in November 1763, they set up their equipment – two transits, two reflecting telescopes, and a zenith sector. Within a month, they had measured the southernmost latitude of Philadelphia – 39° 56′ 29.1″ N – and began the survey proper.

During the first few months, Mason and Dixon followed the old "Temporary Line" surveyed in 1739 by Benjamin Eastburn. This brought them through small townships such as Darby, Providence, Thornbury, West Town, and West Bradford. From there they continued to travel westward, as they were directed, along the parallel of latitude as far as the country was inhabited. The two continued until September of 1767 where, at Dunkard Creek, their Indian guide informed them it was the will of the Six Nations that the survey be stopped. They returned to England a year later in September 1768.

Because of their experience and their quality observations in 1761, Mason and Dixon were again asked to participate in an expedition for the 1769 Venus transit. Mason did not wish to participate; at the last minute, he grudgingly agreed to travel to County Donegal in Ireland. Only Dixon was willing, and he observed from the island of Hammerfest, off the Norwegian coast.

After the transit, Dixon's life was very quiet with a local surveying practice. He returned home to Cockfield, where he died, unmarried. Dixon was buried at the Friends' Burial Ground, Staindrop.

Francine Jackson

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Dollond, John

Born **Spitalsfield, (London), England, 10 June 1706**
Died **London, England, 30 November 1761**

The achievement for which the optician John Dollond is best remembered is his invention of the achromatic refracting telescope. Dollond's father, Jean, was an immigrant from Normandy. John privately studied Latin, Greek, anatomy, theology, algebra, geometry, optics, and astronomy. He married Elizabeth Sommelier, who bore him two sons (Peter and John) and three daughters (Susan, Sarah, and one with name unknown).

At the age of 46, John joined his eldest son **Peter Dollond** who had set up shop as an optician. By the following year, John had made two new devices that could be used with telescopes. The first was an ocular with additional lenses that led to a reduction in the spherical and chromatic aberration. The second was a divided object glass micrometer, also called a heliometer. In this device, the objective of a telescope is divided into two halves, one or both of which could be driven laterally, thus giving a double image. By measuring the relative distance the lenses moved, for example, to bring the images of two stars together, one could calculate their angular separation. The heliometer was extensively used to measure the seasonal variations in the angular diameter of the Sun and also was applied to the measurement of the diameter of planets, the spheroidal shapes of planets, and the elongations of Jupiter's satellites.

Isaac Newton had noticed that the various colors comprising white light were not all brought to a focus by a lens at the same place, resulting in a blurred image with colored borders. Furthermore, his experiments seemed to indicate that there was no way to avoid that problem except to use a reflecting telescope. But after Newton's pronouncement was brought into question by **Leonhard Euler** and Samuel Klingenstierna, Dollond performed experiments with prisms of various types, which indicated that it was indeed possible to make a lens corrected for chromatic aberration by combining a converging lens of crown glass with a diverging lens of flint glass. For this achievement, he was awarded the Royal Society's Copley Medal. Although there was a controversy over his priority in the invention, he was granted a patent and began producing high-quality achromatic telescopes.

Dollond became optician to King George III. Instruments from the Dollond shop went to astronomical observatories all over the world and were produced long after his death.

M. Eugene Rudd

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Dollond, Peter

Born **London, England, 24 February 1730 or 1731**
Died **Kennington, (London), England, 2 July 1820**

Peter Dollond was a noted English optician and instrument maker. The eldest son of **John Dollond** and Elizabeth Sommelier, he married Ann Phillips. They had two daughters, Louise and Anne.

By the age of 20, Peter Dollond had started in business as an optician, a business his father joined a few years later. After his father's invention of the achromatic lens, Peter made large numbers of achromatic refracting telescopes of many sizes and designs. He developed a triplet achromatic lens (1765) that also had less spherical aberration. These were the finest telescope objectives available at the time. But because of the difficulty in obtaining good quality flint glass, he was able to make only a few of these in sizes with apertures as large as 4 in. and 5 in., one of which was purchased by the Royal Observatory at Greenwich. Dollond's instruments were used to observe the transit of Venus during captain James Cook's voyage to Australia.

During the Napoleonic Wars, Dollond supplied the army and navy with theodolites, sextants, and microscopes and also introduced a telescope with several brass drawtubes, which was extensively used by the military because it was compact. He made improvements to **John Hadley**'s quadrant to make it more serviceable at sea (1772) and added an apparatus to the equatorial instrument to correct for errors due to the refraction of the atmosphere (1779). **Nevil Maskelyne**, the Astronomer Royal, presented descriptions of these design improvements to the Royal Society. Dollond is also credited with a number of minor improvements to telescopes and other intruments.

In addition to achromatic telescopes, Dollond's workshop turned out Gregorian reflecting telescopes, sextants, theodolites, transits, and many other optical instruments. A heliometer constructed by him was used at the Royal Observatory at the Cape of Good Hope until 1868. Using a similar instrument in 1812, **Friedrich Bessel** measured the distance between the components of 61 Cygni. Dollond, like his father, served as optician to King George III. Peter was also a fellow of the American Philosophical Society.

M. Eugene Rudd

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Dombrovskij [Dombrovsky, Dombrovski], Viktor Alekseyevich

Born **Rostov Velikij, Russia, 30 September 1913**
Died **Leningrad (Saint Petersburg, Russia), 1 February 1972**

Soviet astronomer Viktor Dombrovskij observed polarized light (evidence of synchrotron radiation) coming from the Crab Nebula. His discovery was the direct result of a prediction made by **Iosif Shklovsky**.

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Don Profeit Tibbon, Profatius

➜ **Jacob ben Makhir ibn Tibbon**

Donati, Giovan Battista

Born **Pisa, (Italy), 16 December 1826**
Died **Florence, Italy, 20 September 1873**

Giovan Donati was an observational astronomer and an early contributor to stellar spectroscopy. Pictures of the comet that he discovered are still widely reproduced in astronomy textbooks.

Donati was the son of Dr. P. Donati of Pisa. After preliminary studies at the University of Pisa under M. Mossotti, Giovan devoted himself to mathematics and original analytical researches. In 1852 he joined professor **Giovanni Amici** at the Observatory of the Museum of Natural History, then known as La Specola. Two years later, Donati was made an *aide-astronome*, and following his discovery of the magnificent naked-eye comet C/1858 L1 that bears his name, *astronome-adjoint*. (He first saw the comet as a telescopic object on 2 June 1858.)

Donati succeeded Amici as director in 1864, the year he was elected an associate of the Royal Astronomical Society. During the period 1864–1872, Donati made strenuous efforts to set up a new national observatory at Arcetri adapted to the requirements of modern astronomy and terrestrial physics. His ambition was finally realized on 27 October 1872 when the Astrophysical Observatory at Arcetri, Florence (located near the house where **Galileo Galilei** died), was inaugurated.

Donati was a pioneer in the field of stellar spectroscopy, a subject to which he wholly devoted himself following his visit to Spain to observe the total eclipse of the Sun in June 1860, and to which he made important contributions. The experience gained in this area induced him to examine the phenomena of scintillation. Between 1852 and 1864, he discovered five comets (including that which has his name), and during the early morning hours of 5/6 August 1864, he became the first to obtain a spectroscopic record of a comet when he observed and drew the spectrum of comet C/1864 N1 (Tempel). In 1869 he noted from observations of the great aurora of 4/5 February 1872 that certain phenomena were inconsistent with a purely atmospheric origin, something that led him to formulate what he called a cosmic meteorology. Between 1854 and 1873, Donati published roughly 100 papers, many of which were devoted to astrophysical subjects, atmospheric physics, and comets.

Donati was taken ill with Asiatic cholera while returning from Vienna, where he had represented the Italian government at the International Congress of Meteorology. Although seriously ill, he was enabled to return to his home and family at Florence, near the new observatory, but within a few hours succumbed to the disease.

Richard Baum

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Donner, Anders Severin

Born **Kokkola, (Finland), 5 November 1854**
Died **Helsinki, Finland, 15 April 1938**

Finnish astronomer Anders Donner should perhaps be remembered as the astronomer primarily responsible for completing on time one of the first zones of the *Carte du Ciel* project. His parents were Anders Donner and Hilda Rosina Louise Malm. He married Elin Maria Wasastjerna in 1883, and they had six children.

Anders Donner lost his father early. His mother remarried and moved to Helsinki. Donner graduated from the University of Helsinki in 1875 and studied mathematics in Germany, in Leipzig, Königsberg (today Kaliningrad in Russia), and Berlin. In 1877/1878, Donner assisted his former professor of astronomy **Karl Krüger** in astronomical observations at Gotha in Germany. Donner defended his doctoral thesis on mathematics in Helsinki in 1879.

Donner concentrated on theoretical astronomy, especially on celestial mechanics, in the Observatory of Stockholm under the guidance of **Johan Gyldén**. Donner was appointed professor of astronomy at the University of Helsinki in 1883.

Oskar Backlund, who worked at the Pulkovo Observatory in Russia, drew Donner's attention to the possibilities that a brand new observation technique, *i. e.*, photography, offered to astronomy. Photographs of an object were permanent documents that could be looked at later, and the long exposure revealed objects moment to be seen with eyes, even through a powerful telescope. The importance of the method was soon understood, an international conference was held in Paris in 1887, and a catalog and sky map project of stars based on photography was launched. Donner joined the project that is known by its French name *Carte du Ciel*.

For the program, a so called standard astrograph (a kind of telescope) was purchased by the Observatory of Helsinki, and the program started in 1890. The sky was divided among 19 observatories, and Helsinki got the zone between +39° and +47° declination. The aim was to produce a catalog in which the positions of all stars brighter than the 11th magnitude would be measured with great precision, and also their brightness would be given. In addition to that, a map would be made in which all stars brighter than the 14th magnitude would be shown. There were 1,008 areas to be photographed in the Helsinki Zone.

All of the required catalog plates had been photographed in Helsinki by 1896, and the maps were completed in 1911. But the most onerous work was to measure the positions and brightnesses of the stars on the plates and to calculate their coordinates and magnitudes with great precision for inclusion in the catalog. While carrying out this work, Donner developed and published many new methods of handling the large quantities of data involved. Photographs of the sky for many other studies were also taken at Helsinki and sent to the observatories that had requested them. Publication of the Helsinki Zone of the *Carte du Ciel* (astrographic catalog) began in 1903 and was completed in 1939. The 12-volume catalog contains 284,663 stars, and Donner eventually invested a considerable sum from his own resources in the project.

The workload of the project proved much bigger than was expected in the beginning, and many observatories did not finish or postponed their work. As the *Carte du Ciel* of Helsinki was the only one to be completed in decades, the program did not produce the kind of complete material that was originally hoped for, to be used for instance in study of the structure of the Milby Way.

On Donner's initiative, the photography of sky zones was restarted in 1909. By comparing the new plates to the older ones, proper motions of stars, whose positions had changed during the years, would be found. Donner's closest colleague, professor Ragnar Furuhjelm (1879–1944), published in 1916–1947 catalogs of over 4,000 proper motions of stars. Research on proper motions of stars has continued in Helsinki down to the present.

Donner was the rector and chancellor of the University of Helsinki and a member and elected official of many scientific societies. He strongly influenced the organization of many scientific fields in Finland and was also a key figure in the economic life of the country.

Tapio Markkanen

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Doppelmayer [Doppelmayr], Johann Gabriel

Born **Nuremberg, (Germany), *circa* 1671**
Died **Nuremberg, (Germany), 1 December 1750**

Johann Dopplemayr is known for his terrestrial and celestial maps and globes. For almost half a century, he was professor of mathematics at the Aegidien Gymnasium in his native city. He published various works on mathematics and physics, as well as on geography and astronomy, in which he exhibited Copernican sympathies. Doppelmayer enjoyed a fruitful collaboration with Johann Baptist Homann (1664–1724), who produced a variety of important atlases, maps, and globes. Doppelmayer's best-known work is his *Atlas Coelestis* (1742); he also produced a book about the Moon describing lunar features using the nomenclature of **Johann Hevel** and **Giovanni Riccioli**.

Ednilson Oliveira

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Doppler, Johann Christian

Born **Salzburg, (Austria), 29 November 1803**
Died **Venice, (Italy), 17 March 1853**

Johann Doppler first proposed the famous effect named after him, which predicted a change in the frequency of sound or light waves emitted by a source when either the observer or the source is in motion along the line of sight. Doppler was the son of a stonemason and educated in Salzburg and Vienna. He held several academic appointments during his short life: first as a professor of mathematics at the Realschule (state secondary school) in Prague (from 1835), as a professor of mathematics at the State Technical Academy (from 1841) also in Prague, in 1847 at the Mining Academy in Chemnitz, and finally from 1850 as professor of experimental physics at the University of Vienna.

It was during his time at the Technical Academy in Prague that Doppler delivered a lecture, on 25 May 1842, to the Royal Bohemian Scientific Society entitled "On the colored light of double stars and of some other stars of the heavens." The lecture was published in the society's proceedings in 1843 and contained a mathematical derivation of the result that the frequency change would be proportional to the radial motion of either source or observer.

Although the Doppler effect was soon confirmed for sound waves (by C. H. D. Buys-Ballot in the Netherlands, who in 1845 played wind instruments on passing trains), its validity for light was a source of considerable controversy for many years. The early objections came notably from Buys-Ballot and also from a fellow Austrian of geometrical optics fame, J. Petzval.

Armand Fizeau in France delivered a lecture in 1848 on the wavelength (or frequency) shift expected in the absorption lines that had been observed by **Joseph Fraunhofer** in the spectra of the Sun and a number of stars, if such bodies were in motion. Unfortunately, his lecture was not published until 1870, so remained largely unknown. In France, the Doppler effect is today often referred to as the Doppler–Fizeau effect, evidently for good reason.

In Germany, Ernst Mach came to the same conclusion as Fizeau in 1860, as did **James Maxwell** in Scotland a few years later. None of these contributions invoked color changes for moving stars, but instead predicted small line shifts that might be detectable in the spectroscope. It should be recalled that Doppler's paper had made no reference to spectroscopy, but only to the brightness and color changes of stars in motion relative to those at rest. Indeed, in 1842 the only significant observations of stellar spectra had been those of Fraunhofer in 1814/1815 and again in 1823. This made Fizeau's and Mach's insight into the application of the Doppler principle to stellar spectroscopy, which only experienced a rebirth from about 1862, all the more remarkable.

Doppler himself did not live to hear of this substantial modification to his effect when applied to starlight. His work was still enshrouded in controversy when he died while visiting Venice in hopes of improving his health. Both **William Huggins** in London and **Angelo Secchi** in Rome had around 1868 attempted to measure line shifts visually for bright stars through a spectroscope, but the shifts were too small to be reliably determined or substantiated.

Not until the 1870s did the careful observations of Secchi (1870) and **Hermann Vogel** (1872) demonstrate the reality of the line shifts from the spectrum of the equatorial region of the Sun arising from solar rotation. This demonstration opened up the way for a major new line of astronomical research – the measurement of Doppler shifts and hence of line-of-sight velocities for stars. This type of investigation was successfully undertaken from 1888 by Vogel and **Julius Scheiner** using spectrum photography at the newly established Potsdam Astrophysical Observatory. The discovery of spectroscopic binary stars by Vogel and **Edward Pickering**, using the Doppler effect, was also a major application of Doppler's work from this time.

It would be wrong to suppose that Doppler completely misinterpreted the application of his effect to astronomy. For if stars were in fact to have significant velocities compared with the velocity of light, then Doppler's predictions of color and magnitude changes would be upheld. Indeed, this is just the case with quasi-stellar objects. If the red shifts of these objects are cosmological, then they are receding at relativistic velocities and the photometric properties are affected accordingly, much as Doppler would have predicted.

John Hearnshaw

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Dörffel, Georg Samuel

Born **Plauen, (Sachsen, Germany), 21 November 1643**
Died **Weida, (Thuringen, Germany), 6–16 August 1688**

Georg Dörffel's contributions to astronomy concern, above all, investigations into the orbits of planets and comets. Dörffel was the son of an evangelical clergyman. His father had studied in Frankfurt an der Oder, Königsberg, in Denmark, Holland, and Sweden. He became the private tutor and envoy for the prince electors of Brandenburg, and also worked as a country pastor in a few villages around Plauen. Dörffel's mother had been twice married but had lost her previous husbands to the plague. Georg Dörffel was the only one of four children to reach adulthood. He attended the city school in Plauen and studied in Leipzig and afterward in Jena. Studying under **Erhard Weigel**, he obtained his master's degree in 1663 by defending his thesis entitled *Exercitatio philosophica de quantitate motus gravium*. Dörffel concluded his studies in 1667 by receiving a bachelor of theology from the University of Leipzig.

After his father's death in 1672, Dörffel established himself as a successful rural clergyman and priest, having to give more than 100 sermons a year. In 1684, he was appointed superintendent in Thuringia by the rulers of Saxe-Zeitz. After the death of his first two wives, Dörffel married a third time, a marriage that produced ten children.

Dörffel's interest in astronomy was already apparent at a very early age. His first two astronomical works, published in 1672, dealt with that year's comet (C/1672 E1) and were followed by five more astronomical studies in 1677, 1680, 1681, and 1682. The subsequent publications contained observations about the total lunar eclipse of 21 February 1682, the mathematical prediction of the lunar eclipse on 27 June 1684, the "Neue Mondwunder" (the appearance of a halo) on 24 January 1684, and a study of the principles governing the parallaxes of the planets and comets. Preserved in manuscript are Dörffel's calculations of the path of the fireball on 22 August 1683, which he compiled based on observations made by both himself and others, and which illustrate Dörffel's efforts in studying a phenomenon that had hardly been considered previously. In addition, astronomy always remained for him a leisure activity that he could practice only after he had completed his professional duties, which he took very seriously.

Although the cosmic nature of comets was recognized in the mid-17th century (especially by the successors to **Tycho Brahe** and **Christoph Rothmann**), the form of their movement remained unknown, even when it was accepted around 1600 that they had orbits resembling those of the planets (*e. g.*, by **Helisaeus Roeslin** and Johannes Krabbe).

The comet discovered by **Gottfried Kirch** on 14 November 1680, C/1680 V1, fueled investigations into the principal assumptions about comet orbits. The 1680 event could be observed both before (24 November 1680) and after its passage through perihelion (on 11 December 1680). However, the first problem consisted in recognizing the appearance of one and the same comet. Most astronomers (as well as Kirch himself) believed that there were two comets – one in the evening sky and another in the morning sky.

Dörffel observed both apparitions very carefully. He predominantly used the typical protractor of his time, and at times made observations with the naked eye, and possessed at least two telescopes with focal lengths between 1.4 and 2.3 m (with which he could achieve enlargements between 20 and 52 times). His measurements of the comets do not display especially great accuracy, but Dörfel was in a position to evaluate carefully all sides of the data that were available to him. In his *Astronomische Betrachtung des Grossen Cometen* …, he drew the following conclusions:

(1) The observations of comets in 1680 and 1681 did not involve two comets but two appearances of a single comet moving around the Sun. Dörffel refers, in this research, to Occam's razor, *i. e.*, "one thing should not be made many without it being necessary."
(2) The orbit of this comet is a parabola, in which the Sun occupies the focal point. Only by assuming the existence of a single comet is it possible to recognize the parabolic movement of this heavenly body. By assuming the existence of two comets, earlier researchers were led to believe that comets had a linear or, at best, a slightly bent path.

As the comet C/1680 V1 was a so called sungrazer, its orbit did, in fact, very strongly approximate the form of a parabola, as a result of which Dörffel was proven right in this case. The deduction of the parabolic orbit of the comet gives the focal point of the orbit, the point occupied by the Sun, a special significance.

Concerning the nature of comets themselves, Dörffel appeared temporarily to agree with notions describing them as "disks," such as the one advanced by **Johannes Hevel**. He had not found a parallax and was convinced by others, insofar as he held comets to be heavenly bodies. His avowal of **Nicolaus Copernicus** was a hesitant one, and he had earlier also refused to accept Brahe's geo-heliocentric system.

Dörffel settled questions about the orbits of comets on primarily empirical grounds, on the basis of his own observations, and found the correct means of describing the orbit of comet C/1680 V1. However, this discovery subsequently received little recognition, especially since **Isaac Newton** established, a little later, the correct methods of describing the motion of heavenly bodies. Only at the end of the 18th century was Dörffel's achievement appreciated by German and French astronomers, and his lasting significance in the history of astronomy made apparent. In addition to his astronomical studies, Dörffel published several theological works including at least one funeral sermon and a book on the Hebraic language (*Tirocinium accentuationis, ad lectionem Biblicam practice accomodatum*, Plauen, 1670).

Jürgen Hamel

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Dortous de Mairan, Jean-Jacques

➜ **Mairan, Jean-Jacques**

Dôsitheus of Pêlousion

Flourished **Pêlousion (Tell el-Farama, Egypt), 230 BCE**

Dôsitheus was a student of Konon (**Conon**) of Samos and a correspondent of **Archimedes** of Syracuse. He wrote and observed in Alexandria, and perhaps on the island of Kos, but nothing further is known of his life. The name, meaning "god-given," is common, but all other prominent Ptolemaic bearers were Jewish, so it may translate as Nathaniel. Pêlousion, at the easternmost mouth of the Nile, was an important coastal border fortress and customs station of Ptolemaic Egypt. During Dôsitheos's lifetime, Pêlousion was often the point of departure for Ptolemaic attacks on the neighboring Seleukid Kingdom (in the wars of 274–271, 260–253, 246–241, and 221–217 BCE).

After Konon died, Archimedes resorted to Dôsitheus as the addressee of his mature works – *On the Quadrature of the Parabola*, *On the Sphere and Cylinder* (two books, separately addressed), *On Spirals*, and *On Conoids and Spheroids*. In turn, Dôsitheus solicited proofs from Archimedes, who attributed to him not expertise but only familiarity with geometry. Dôsitheus's astronomical contributions chiefly concerned the calendar, on which he wrote three works – *Appearances of Fixed Stars* (rising and setting dates), *Weathersigns* (seasonal weather predictions based on astronomical phenomena), and *On the Eight-year Cycle of Eudoxos* (all lost). Notes from the first and second are preserved in the calendar appended to **Geminus**'s *Introduction*, in **Pliny** and in **Ptolemy**'s work of the same name (usually cited as *Phaseis*). Dôsitheus is also attested to have written a work *To Diodoros* (an exceedingly common name), apparently giving information on the life of **Aratus**.

Paul T. Keyser

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Douglass, Andrew Ellicott

Born **Windsor, Vermont, USA, 5 July 1867**
Died **Tucson, Arizona, USA, 20 March 1962**

Andrew Douglass's primary training and lifelong ambition was in astronomy; he made substantial contributions to that discipline, particularly in demonstrating and articulating the impact of local atmospheric conditions on the effectiveness of astronomical observatories and in founding the Steward Observatory at the University of Arizona. However, Douglass is better remembered today as the founder of the science of dendrochronology, or tree-ring dating, as he spent a lifetime seeking to prove that the 11-year solar cycle affects the Earth's climate and that tree-ring evidence would demonstrate that. His biographer, George Ernest Webb, argues that it was tree-ring dating that was Douglass's only significant contribution to science.

Douglass was born in a privileged family descended from Vermont clergymen and educators. He was named after his paternal great-grandfather, **Andrew Ellicott** (1754–1820), a talented astronomer and surveyor. Ellicott assisted Pierre L'Enfant in platting what eventually became the capitol city of Washington. The fifth of six children, Andrew's father was the Reverend Malcolm Douglass, who would later become a president (1871–1872) of Norwich University, Northfield, Vermont. Andrew's mother, Sarah Elizabeth Douglass, was the daughter of Benjamin Hale, president of Hobart College, Geneva, New York. His grandfather, David Douglass, had been president of Kenyon College (Gambier, Ohio). Andrew was a brilliant student who achieved honors at Trinity College in physics, geology, and astronomy. Although he had no formal degrees beyond the baccalaureate level, he was the recipient in later years of an honorary doctorate bestowed upon him by his *alma mater*.

Douglass spent his first 5 postgraduate years as an assistant at the Harvard College Observatory in Cambridge, Massachusetts. His tenure at Harvard included a successful foreign assignment in Arequipa, Peru. Douglass accompanied **William Pickering**, who established a field station there for the university. After a year in Peru, during which Douglass acquired a taste for archeology and anthropology, he accompanied Pickering on a circuitous tour of European observatories before returning to Harvard. Back in Cambridge, Douglass reduced the observations that continued to flow in from Peru.

In 1892, **Percival Lowell** decided to expand upon his own interests as an amateur astronomer and take up the observation of Mars. By January 1894, that interest had expanded to involve assistance from Harvard. On Pickering's recommendation, Lowell sent Douglass to the Arizona Territory in February to assess possible sites for an observing station for the viewing of Mars at the 1894/1895 opposition. In April 1894, on the basis of Douglass's observations made at various locations around the Territory, Lowell selected Flagstaff as the site of the temporary observing station that eventually became the Lowell Observatory. Douglass was given the task of turning a hilltop that was only a mile west of the center of town into a temporary astronomical observatory, a task that he accomplished successfully by soliciting the cooperation of Flagstaff officials and residents. Observations of Mars began in late May and continued until the end of that opposition in April 1895.

Although Lowell's needs dominated use of the telescope in favorable weather, Douglass participated in the observation campaign and remained at Flagstaff for the entire opposition event. At Lowell's behest, Douglass made two trips to Mexico, searching for an even better site for a formal installation, while interspersing these times with returns to Harvard and data-reduction and writing efforts. As it happened however, Douglass remained in Flagstaff for a number of years managing what was becoming the permanent Lowell Observatory while Lowell himself was recovering from a nervous breakdown.

During this period, Douglass reduced observations, published the first two volumes of the *Publications of the Lowell Observatory*, and wrote numerous journal and periodical articles about the work of his mentor's observatory, planetary astronomy, and other topics. Indeed, **Edward Barnard** thought so highly of Douglass's observations and writing skills that he encouraged Douglass to send more of what Barnard "esteem[ed] … among the freshest and best that we get from any source." Douglass continued to observe the satellites of Jupiter especially seeking to better understand their particular characteristics. It was during this time that his relationship with Lowell gradually unwound under the pressure of Douglass's increasing sensitivity to reactions from the rest of the astronomical community to Lowell and his first book on Mars, controversy about the clouds observed on the terminator of Mars, Lowell's insistence on the seeming presence of canals on the Red Planet, Lowell's resistance to experimental observational work with model planets, *etc*. Of particular note was Douglass's sighting of a bright flash along the Martian terminator that Lowell took to be a "message" sent from civilizations he believed present on the planet. Lowell published a book on the subject and was ridiculed by many in the community. **George Hale** already had refused to publish Lowell's works in his fledgling *Astrophysical Journal*. But it was an unfortunate instance of Lowell's receiving a copy of a letter critical of him written by Douglass to Lowell's brother, William L. Putnam, seeking intercession concerning Lowell's penchants with Mars, which finally led Lowell to fire Douglass. This was primarily because Lowell had become an obsessed devotee of **Giovanni Schiaparelli** and his *canali*, infamously mistranslated as canals, even though **William Campbell** had shown by spectroscopic analysis that the atmosphere of Mars was more akin to that of the Moon than to that of Earth. Little water vapor seemed present. Douglass could not abide Lowell's insistence upon there being civilizations on Mars. Lowell's pique led to his sudden termination of Douglass in July of 1901, thus leaving the younger astronomer trapped in the Wild West and unemployed after some 17 years in his chosen discipline, with 8 of those years spent in Flagstaff.

He was for a short time jobless, as there were no openings in astronomy on either coast of the United States, and so Douglass had to find a way to sustain himself in Flagstaff. He eventually won election as a local probate judge, and later taught at what is now Northern Arizona University. On 1 July 1905, he married the former Ida Whittington of Baltimore, Maryland and, in 1906, moved to the University of Arizona, Tucson, after 12 years in Flagstaff. Douglass remained at the university in Tucson for the rest of his extraordinarily long and productive life, although for many decades he continued to hope to return to his native Northeast, often applying for openings in various observatories or universities there.

It was during the years between the Lowell Observatory and the move to Tucson that Douglass became interested in tree rings. This led him to the *de novo* creation of the science of tree-ring dating, or dendrochronology, which became his primary concern as a technique to study the 11-year solar cycle, his all-consuming passion in astronomy. The dating of the great pueblos of the American Southwest, which had been engineered by the ancient Anasazi Indians and a problem that had vexed North American archaeology since the "cliff dwellings" and similar structures were first discovered, constituted Douglass's greatest success story for dendrochronology (late 1920s). However, its role as a tool for astronomy was never realized. McGraw has stated, "the climatological records in the rings of trees would … be his *entrepot* to proving that the possible relationship of the 11-year sunspot cycle to weather patterns on Earth was indeed a reality." He never succeeded in this; nor has anyone else done so beyond reasonable doubt, to this day.

Douglass held numerous positions at the University of Arizona, from professor to dean to director of Steward Observatory, including even its presidency for a short time. He sought to found an observatory almost from the day of his arrival in Tucson and, while it took two decades to actually open the facility, he was successful in obtaining funding (in 1916) from a Mrs. Lavinia Steward, whose deceased husband had been an amateur astronomer. Getting the primary instrument built, let alone the protective structure for it, was a prolonged and convoluted project, but when completed the Steward Observatory had a 36-in. Brashear/Warner & Swasey reflecting telescope. It was one of the larger telescopes available in US astronomical research institutions at the time of the observatory's opening in April 1923.

Douglass left two physical, as well as intellectual, monuments to his long and busy career, the Steward Observatory and eventually (1935) the Laboratory of Tree-Ring Research, both on the campus of the University of Arizona and both of which remain major forces in their respective areas. In his efforts to study the 11-year solar cycle, however, Douglass also invented two optical instruments – the periodograph and its successor the cyclograph – to study the periodicity and cyclicity he believed he had found in tree rings.

Donald J. McGraw

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Draper, Henry

Born **Prince Edward County, Virginia, USA, 7 March 1837**
Died **New York, New York, USA, 20 November 1882**

Henry Draper, a physician by profession and prominent American amateur astronomer and telescope maker, recorded the first photographic images of the Orion Nebula and of the spectrum of a star (Vega). His name adorns the Henry Draper catalog of stellar spectral types.

Draper's father, **John Draper**, was an accomplished physician, chemist, and professor at the University of the City of New York (later New York University). Draper's mother was the former Antonia Coetana de Paiva Pereira Gardner, whose own father was personal physician to Dom Pedro I, Emperor of Brazil. Draper's elder brother, John Christopher, became a noted physician and chemist; a younger brother, Daniel, distinguished himself in meteorology. His neice **Antonia Maury**, was one of the three women who developed the system of spectral classification used in the Catalogue

At the age of 13, Henry Draper assisted his father in photographing microscope slides for a textbook. He later used similar techniques for his own medical thesis on the spleen in 1857. Draper spent a year abroad after completing his medical training at age 20; he could not receive his diploma before turning 21. His travels included a tour of the estate of **William Parsons** (Third Earl of Rosse) in Ireland, where he examined the world's largest telescope, the 72-in. Leviathan reflector. Draper returned home determined to exploit his knowledge of photography for astronomical purposes. He pursued his goal with vigor, building an observatory on his father's estate at Hastings-on-Hudson, New York. However, these activities did not prevent him from fulfilling his professional duties, first as a physician at Bellevue Hospital and later as both professor and dean of medicine at the University of the City of New York.

In September 1858, shortly after his return from Europe, Draper began the construction of a mirror grinding machine of Lord Rosse's design. Early experiments in casting and polishing a 15½-in. speculum metal mirror came to a disappointing end when water in the mirror mount froze and cracked the finished mirror into two pieces. Draper's father recounted the sad story to **John Herschel** during a visit to England. Aware that **Jean Foucault** and Karl August Steinheil (1801–1870) had each experienced success using parabolic silvered glass mirrors as telescope objectives, Herschel suggested that Draper consider changing to glass. Draper began to experiment with glass, making over 100 mirrors as he tried various grinding, polishing, and testing procedures. He studied the effects of glass type, temperature during the polishing and testing phases, and other variables in the process. His initial grinding machine produced too many zones in mirrors and was replaced with a machine designed by **WilliamLassell**, although that too was later replaced with a simplified version that is now known as the Draper machine. After a visit to Hastings-on-Hudson, Smithsonian Institution director **Joseph Henry** asked Draper to publish a memoir on what he had learned in all this experimentation. Draper's valuable memoir on construction of his 15½-in. reflecting telescope, published by the Smithsonian Institution, guided telescope makers for several generations.

Draper's work was interrupted in 1862 when he volunteered for service in the Union Army as a regimental physician. His frail physical condition could not withstand the strain, however, and he returned to his home after 9 months.

In 1863, Draper made over 1,500 photographic exposures of the Moon. Some of those exposures were sharp enough to stand enlargement up to a lunar diameter of 50 in.

Draper married Anna Mary Palmer in 1867. A wealthy socialite, Anna proved as able a laboratory assistant as she was a hostess. The Drapers often entertained a stellar cast of scientists and celebrities in their home. They had no children.

In the fall of 1867, Draper began work on a 28-in. mirror. When completed in May 1872, the optics provided for use at both the Newtonian and the Cassegrain foci. Soon after the large reflector was completed, Draper took several exposures of the bright star α Lyrae (Vega). He placed a quartz prism slightly ahead of the Cassegrain focus, and after several trials, was rewarded with the first stellar spectrum ever photographed. The same year, Draper recorded the solar spectrum photographically for the first time. His solar spectrum was the best available between 1873 and 1881; he had it reproduced with the photomechanical Albertype process so that it could be distributed for comparison purposes.

Throughout the 1870s, Draper continued to apply photography and spectrography to astronomical objects whenever time permitted. The death of Anna's father left Draper with many time-consuming duties as the executor of the estate. Eventually, Draper resigned his position as dean of the medical school and accepted a position as professor of analytical chemistry in 1873. That change was likely also prompted by Draper's acceptance of responsibility for photographic applications during the US transit of Venus expeditions. During the remainder of the 1870s, Draper accumulated spectra of the Orion Nebula, the Moon, Jupiter, Mars, Venus, and numerous bright stars. He was also the first to combine photography with the slit spectroscope to create what he then called a spectrograph.

Draper's scientific judgment failed him only once in a significant manner. In 1877, he claimed to have identified 18 emission lines of oxygen in the spectrum of the Sun, although other spectroscopists disagreed with his identification. Even a trip to London to display his results for the Royal Astronomical Society failed to persuade Draper's critics. This was perhaps the one case in which Draper's enthusiasm carried him too far. However, it is likely consistent with his general approach. Draper pushed the state of the art in photography, instrumental optics, and telescope clock drives, the steadiness of which is essential for long photographic exposures.

Draper is best known for obtaining the first photograph of an astronomical nebula, recording the Orion Nebula on the night of 30 September 1880. His first image, a 50-min exposure, was not very impressive, but Draper improved upon it rapidly. His last exposure of 137 min on 14 March 1882 showed considerably more nebulosity and faint star detail. Further refinements in photographing the Orion Nebula were achieved by **Andrew Common** and **Isaac Roberts** in England after Draper's untimely death. Draper also captured the first wide-angle photograph of a comet's tail, and the first spectrum of a comet's head, both on the Great Comet C/1881 K1 (Tebbutt). In both his photography and his spectrography, Draper was an important pioneer in astrophysics.

At the height of his career, while pursuing increasingly detailed photographs of the Orion Nebula, Draper was taken ill after a hunting trip to the Rocky Mountains and died of double pleurisy. His wife later established the Henry Draper Memorial to support photographic and spectrographic research in astronomy. The memorial funded both the *Henry Draper Catalog*, a massive photographic stellar spectrum survey carried out by **Annie Cannon** and **Edward Pickering** still in wide use today, and the Henry Draper Medal, which continues to be awarded by the National Academy of Sciences for outstanding contributions to astrophysics.

Draper received numerous awards, including honorary law degrees from New York University and the University of Wisconsin, a Congressional medal for directing the US expedition's efforts to photograph the 1874 transit of Venus, and election to both the National Academy of Sciences and the Astronomische Gesellschaft. In addition, he held memberships in the American Photographic Society, the American Philosophical Society, the American Academy of Arts and Sciences, and the American Association for the Advancement of Science.

Steven J. Gibson

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Draper, John William

Born **Saint Helens, (Mersey), England, 5 May 1811**
Died **Hastings-on-Hudson, New York, USA, 4 January 1882**

John Draper captured the first photographic astronomical image of any type and stated, qualitatively, the relationship between the temperature and the spectrum of a solid body.

After immigrating to Virginia, USA, with his widowed mother in 1832, Draper was trained as a physician at the University of Pennsylvania. He taught chemistry at Hampton-Sydney College for 3 years before moving, in 1839, to New York, where he was a professor of chemistry at the University of the City of New York (later New York University). Draper helped found the New York University School of Medicine and served as its president after 1850. He was a pioneer photographer and applied photography in his medical research.

Besides his support and encouragement for his son, **Henry Draper**, John Draper's major contributions to astronomy were twofold. First, his daguerreotype image of the Moon, taken during the winter of 1840, was the first such astronomical image formed anywhere. By 1845, Draper had also captured a daguerreotype image of the solar spectrum. More importantly, in mid-1840 Draper enunciated the principle that solid substances become incandescent as their temperature is raised and emit a continuous spectrum of light that is increasingly refrangible (shifted toward the ultraviolet end of the spectrum). This important principle, which is fundamental to astrophysics, was refined by Draper in 1857 with his assertion that the maximum of luminosity and heat in the spectrum coincide. The American Academy of Arts and Sciences awarded its Rumford Medal to Draper for his work on radiant energy in 1875.

Draper was also a strong defender of science from the encroachment of religious thinking. His 1860 paper on the progress of organisms, presented to the British Association for the Advancement of Science, provoked the famous debate between Bishop Wilberforce and Thomas H. Huxley, but his most popular book was *A History of the Conflict between Religion and Science*.

Thomas R. Williams

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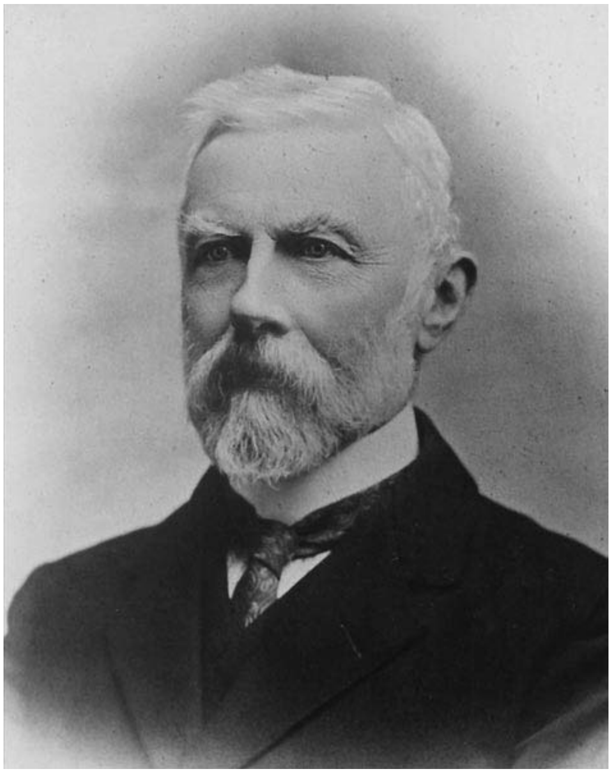
Dreyer, John Louis Emil

Born **Copenhagen, Denmark, 13 February 1852**
Died **Oxford, England, 14 September 1926**

John Dreyer is noted for his meticulous compilation of the *New General Catalogue of Nebulae and Star Clusters* [NGC] and two supplementary catalogs, his important biography of **Tycho Brahe**, his collection of the papers of **William Herschel**, and an authoritative history of astronomy.



Dreyer spent most of his working life in Ireland, although he was born in Denmark to a family with distinguished military connections. His grandfather was an officer in Napoleon's army, and his father, Lieutenant General John Christopher Dreyer, served in the Schleswig-Holstein War in 1864, later becoming Minister of War and Marine in the Danish government.

Dreyer attended school in Copenhagen from age 5 until 17, showing great ability in history, mathematics, and physics. At the age of 14, he happened to read a book about Brahe and his observatories on the island of Hven; this inspired him to devote his life to astronomy. Dreyer paid regular visits to Copenhagen Observatory, where he conversed with the assistant astronomer **Hans Schjellerup**. In 1869, Dreyer entered the University of Copenhagen, where he attended the lectures of **Heinrich d'Arrest**, who supervised his astronomical studies. The following year, Dreyer was presented with the key of the observatory, giving him access to the instruments. His first paper, "On the Orbit of the First Comet of 1870" (C/1870 K1), was published in *Astronomische Nachrichten* in 1872. He was awarded a Gold Medal by the University of Copenhagen for an essay on the question of personal errors in observation.

In 1874, Dreyer succeeded **Ralph Copeland** when he was appointed assistant to **William Parsons** at his observatory at Birr Castle, Ireland, where Dreyer had access to the 6-ft. diameter Leviathan, the largest telescope in the world. The following year in Birr, he married Katherine Tuthill from Kilmore in County Limerick. During the 4 years in Birr, Dreyer published several papers in the journals of the Royal Irish Academy and the Royal Dublin Society. One of these, "On Personal Errors in Astronomical Transit Observations," examined critically the sources of error in making visual observations of transits. Dreyer used both the 6- and the 3-ft. reflectors at Birr to observe star clusters and nebulae; his results were included in the *General Memoir of Observations made from 1848 to 1878*, presented by Lord Rosse to the Royal Dublin Society. In 1877, Dreyer presented the Royal Irish Academy with an important paper containing additions and corrections to **John Herschel**'s *General Catalogue of Nebulae and Clusters.*

In 1878, Dreyer was appointed assistant at Dunsink Observatory in succession to **Charles Burton**. The director, **Robert Ball**, put him in charge of meridian observations with the Pistor and Martins Circle. This work culminated in the publication of the mean positions of 321 red stars as part 4 of *Astronomical Observations and Researches at Dunsink, the Observatory of Trinity College, Dublin*. In 1881, Dreyer and Copeland (now Astronomer Royal for Scotland) introduced an international journal of astronomy entitled *Copernicus*. Although only three volumes were published, several important papers appeared. In particular, Dreyer's paper on "A New Determination of the Constant of Precession" was later acclaimed by **Simon Newcomb**.

In 1882, at the age of 30, Dreyer gained his Ph.D. from the University of Copenhagen and was appointed director of Armagh Observatory in succession to **Thomas Robinson**. Financially, Armagh Observatory was destitute, with no prospect of replacing its aging instruments. Although Dreyer obtained a new 10-in. Grubb refractor in 1884, the lack of funding for an assistant precluded him from a continuation of traditional positional astronomy. Instead, he concentrated on the compilation of observations made earlier by Robinson since 1859, together with many of his own. The *Second Armagh Catalogue of 3300 Stars for the Epoch 1875* appeared in 1886. That same year, Dreyer submitted to the Council of the Royal Astronomical Society [RAS] a supplementary catalog of nebulae.

The council proposed that it would be more convenient if the three existing catalogs were combined into a *New General Catalogue of Nebulae*. Dreyer accomplished this laborious task speedily, and the *New General Catalogue of Nebulae and Clusters, Being the Catalogue of Sir John Herschel, Revised, Corrected and Enlarged* was published in 1888 in the *Royal Astronomical Society Memoirs*. The catalog contained the positions and descriptions of 7,840 nebulae for the epoch 1860. It remains the standard reference used by astronomers the world over. Dreyer later published two Index Catalogs [IC] of nebulae and clusters; the first contained 1,529 new nebulae found between 1888 and 1894 and the second contained 3,857 nebulae and clusters found between 1895 and 1907. NGC and IC numbers are still used as the names of many prominent galaxies, nebulae, and star clusters. Meanwhile, Dreyer struggled with continuing financial difficulties facing Armagh Observatory. He used the 10-in. Grubb refractor for micrometric positional measurements of nebulae with respect to comparison stars, and the results were published in the *Transactions of the Royal Irish Academy*.

As time went on, Dreyer became increasingly interested in the history of astronomy and especially in the life and work of his boyhood hero and countryman, Tycho Brahe. In 1890, Dreyer published a fine biography of Brahe, followed in 1906 by his classic *History of the Planetary Systems from Thales to Kepler*. Dreyer's greatest historical work was a complete Latin edition of the works of Brahe, which he started in 1908; the first volume of the eventual 15-volume series appeared in 1913. This project was interrupted between 1910 and 1912 for work on an edition of the scientific papers of **William Herschel**, sponsored jointly by the Royal Society and the Royal Astronomical Society. Dreyer edited the two large volumes and also wrote the introductory biography.

In 1916, the RAS Council awarded Dreyer its Gold Medal in recognition of his great labors in the preparation of his *Catalogue of Nebulae* and of his contributions to the history of astronomy. In September of that year, Dreyer resigned the Armagh directorship and moved to Oxford, England, where he had access to the excellent facilities of the Bodleian Library for pursuing his historical researches.

Dreyer received the degree of D.Sc. from Belfast and an honorary MA from Oxford. The International Astronomical Union named the lunar crater at 10°.0 N and 97°.9 E in his honor.

Dreyer served on the council of the Royal Astronomical Society from 1917 and as president in 1923 and 1924. During his 2-year tenure he delivered two addresses–the first advocated publishing a new edition **of Isaac Newton**'s collected works and the second justified the award of a Gold Medal to **Arthur Eddington** for his work on star streaming, stellar structure, and general relativity. Dreyer was joint editor with **Herbert Turner** of the *History of the Royal Astronomical Society*, published in 1923; he covered the periods 1830–1840 and 1880–1920.

Dreyer combined a single-minded devotion to astronomy with a gentle and amiable disposition. He was a skilled observational astronomer, an excellent mathematician, a talented linguist, and a gifted writer. The death of his wife in 1923 was a great blow from which he never recovered properly. From the end of 1925, Dreyer's health worsened. He was survived by one daughter and three sons.

Ian Elliott

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Dudits [Dudith, Duditus], András [Andreas]

Born **Buda (Budapest), Hungary, 5 February 1533**
Died **Breslau (Wroćlaw, Poland), 23 February 1589**

Theologian András Dudits wrote a treatise on comets, in which he argued against astrology.

Both parents were of noble origin. Dudits's father, Jeromos Dudits, died in a battle against the Turks, and his mother belonged to the Venetian noble family, the Sbardellat. He studied in Verona and Paris (1550–1553), then occupied high positions in the Catholic church–Canon of Esztergom (1557), Provost of Esztergom (1561), Bishop of Tina (Dalmatia) and Csanád (1562), and Bishop of Pécs (1563). In 1562/1563, Dudits served as the Hungarian representative to the Council of Trent. Later on in the 1560s, he fulfilled a diplomatic mission in Poland. His heretical view that priests should be allowed to marry led to his condemnation from the Catholic church. In 1567, Dudits was converted to the Lutheran faith and married a Polish noblewoman. Emperor Maximilian II retained him as ambassador to Poland, but in 1576 Dudits left the court. Then he lived on his wife's property and was engaged in science and humanities: astronomy, medicine, Graeco–Roman literature, and theology.

Having reconsidered his earlier interest in astrology, eventually Dudits rejected it and argued against astrology. In a treatise on comets (*Commentariolus de Cometarum significatione* …, Basiliae, 1579), Dudits criticized the superstitious belief. He was in extensive correspondence with contemporary scientists, among others with the astronomer **Tadeá Hájek z Hájku**, the mathematician **Johannes Praetorius**, and the physician Crato.

László Szabados

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Dufay, Jean

Born **Blois, Loir-et-Cher, France, 18 July 1896**
Died **Chaponest, Rhône-Alpes, France, 6 November 1967**

French spectroscopist Jean Dufay was instrumental in turning the direction of astronomy in his country to spectroscopy and astrophysics and in promoting the modernization of observing equipment during the years between the world wars. Dufay received his bachelor's degree in 1913 and began advanced work in Paris, but enrolled in the French army in 1915 and was wounded during World War I. He returned to the Faculté des sciences in Paris in 1919, and over the next 9 years, combined research with teaching in the Faculté and several high schools, receiving his Ph.D. in 1928 for work on the light of the night sky with **Charles Fabry** and Jean Cabannes.

Dufay was appointed to an *Aide-astronome* astronomy position at the Observatoire de Lyon in 1929 and became director in 1933. From 1939 to his retirement in 1966, he held simultaneously the directorship at Lyon and that of the newly created Observatoire de Haute-Provence, as well as a professorship in the Faculté des sciences de Lyon. He managed to get both observatories through World War II and German control of France, opposing both the invasion and the resultant racial laws.

Dufay's main influence was on instrumentation and its use. With Louis Grouiller, he turned work at the Observatoire de Lyon toward spectroscopy, and took an active part in promoting and selecting a site for the Observatoire de Haute-Provence, which remained a major French facility for decades afterward.

Dufay's own research interests began with spectroscopy of the light of the night sky and broadened in the direction of nebular and nova spectrophotometry, particularly after he reported the Christmas 1934 discovery of cyanogen (CN) bands in the spectrum of Nova Hercules 1934 (DQ Her). Among his students were Joseph-Henri Bigay (who succeeded him as director at Lyon), Marie Bloch, Nguyen Huu Doan, Renée Herman, Agop Terzan, and Tcheng (Cheng) Mao Lin (future director of the Beijing Observatory), a group of unusual diversity in both gender and national origin for its time.

Adam Gilles

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Dugan, Raymond Smith

Born **Montague, Massachusetts, USA, 30 May 1878**
Died **Philadelphia, Pennsylvania, USA, 31 August 1940**

American astronomer Raymond Dugan is best remembered for his accurate light curves of eclipsing binaries, in which one star passes in front of the other and blocks its light. He was also the first to recognize that the details of such light curves could be analyzed to reveal the heating of one star by the other and to show that distortion of spherical stars into ellipsoids by the gravity of their companions was common.

The son of Jeremiah Welby and Mary Evelyn Smith, a descendant of Miles Standish, Dugan completed his bachelor's degree at Amherst College in 1889. The following 3 years were spent at the Syrian Protestant College (now American University) in Beirut, Lebanon, where Dugan was an instructor in astronomy and mathematics and acting director of the observatory. He returned to Amherst for a master's degree in 1902 and immediately left to pursue his doctorate at Heidelberg, where he studied under **Maximilian Wolf**. As an assistant at the Königstuhl Observatory, Dugan took part in the ongoing search for asteroids and discovered 18 minor planets. On receiving his Ph.D. in 1905, he was hired as an instructor in astronomy at Princeton University, where he stayed for the next 35 years. Appointed as an assistant professor in 1908, Dugan was promoted to professor 12 years later. Dugan married Annette Odiorne in 1909. They adopted two children.

While Dugan is probably best remembered as a coauthor with **Henry Russell** and John Quincy Stewart of the two-volume textbook *Astronomy* first published in 1926, he was instrumental in the development of precise determinations of light curves of eclipsing binaries. A contemporary noted that he had "the world's most accurate photometric eyes." Dugan's approach was to make a thorough investigation of the entire light curve of a few stars rather than to get rough results for many objects. He used Princeton's 23-in. telescope with a polarizing photometer for most of his work. Examples of Dugan's procedure are found among his early studies of RT Persei. The light curve was based on 904 points, each the mean of 16 readings, for a total of some 14,500 measures. The direct methods for determining stellar separations, size, limb darkening, and brightness from light curves that would be developed by **Zdeněk Kopal** and others did not yet exist. Thus, Dugan spent many hours in laborious computations that would now be called model fitting and done by computer.

Among Dugan's discoveries was that the ellipticity of components, first recognized in the very close pair β Lyrae, was a general property of eclipsing variables and that the smaller, but hotter and brighter, component in many systems heated the side of the companion facing it, thus causing the "reflection" effect.

By 1937, Dugan had made over 300,000 settings while his students had made some 200,000 more. Dugan followed a few of his stars year by year as long as he was capable of observing. For many, he found slow changes in their periods.

Dugan was elected a member of the American Philosophical Society in 1931. From 1935 until his death, he served as chairman of the International Astronomical Union's Commission on Variable Stars. From 1927 to 1937, Dugan was secretary of the American Astronomical Society and its vice president from 1936 to 1938.

George S. Mumford

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Dunash ibn Tamim

Flourished **Qayrawān, (Tunisia), first half of the 10th century**

Dunash ibn Tamim is not known to have undertaken any original astronomical research. However, he did write on the subject, and two of his treatises are extant. His monograph on the armillary sphere survives in a single manuscript in Istanbul (*Ayasofya MS 4861*). A partial study was published by Stern (1956). Dunash also wrote a commentary on *Sefer Yeṣira* (The book of creation). Like the rest of his contemporaries, he interpreted laconic and elusive Hebrew treatise as a book on science; consequently, his commentary conveys some basic astronomical knowledge. Dunash's commentary was widely circulated, both in the original Arabic and in Hebrew translations; hence it may have played no small role in the dissemination of some elementary astronomy within the Jewish communities of the Mediterranean basin.

Y. Tzvi Langermann

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Duncan, John Charles

Born **Knightstown, Indiana, USA, 8 February 1882**
Died **Chula Vista, California, USA, 10 September 1967**

John Duncan discovered the expansion of the filaments of the Crab Nebula and several variable stars in the "spiral nebula" M33.

Duncan, son of Daniel and Naomi (*née* Jessup) Duncan, studied at Indiana University, earning his A.B. (1905) and M.A. (1906) degrees. He then proceeded to the University of California at Berkeley, where he studied under Lick Observatory director **William Campbell** and obtained his Ph.D. in 1909. Duncan married Katharine Armington Bullard in 1906. The Duncans had one daughter, Eunice Naomi (Strickler).

While still an undergraduate, Duncan taught at a school in rural Indiana from 1901 to 1903. In 1905/1906, **Percival Lowell**, impressed by the work of Indiana-trained students, established a fellowship for Indiana graduates, and Duncan was named the first Lawrence Fellow at the Lowell Observatory. There, he took part in the first photographic search for a trans-Neptunian planet. Duncan later returned to Lowell to aid with the search in the summer of 1912.

Following the receipt of his doctorate, Duncan was appointed as an instructor at Harvard University from 1909 until 1916 and concurrently at Radcliffe College (1911–1916). From 1916 to 1950, he served as chairman of the astronomy department at Wellesley College and director of its Whitin Observatory. Following his retirement from Wellesley, Duncan became a visiting professor at the University of Arizona's Steward Observatory (1950–1962).

In the tradition of Lick Observatory students of his era, Duncan's dissertation involved a spectrographic study of two Cepheid variable stars, Y Sagittarii and RT Aurigae. To try and explain the asymmetries present in the light curves of these stars, Duncan put forth a new hypothesis that linked the observed changes to supposed interactions between a pair of stars closely orbiting one another. Today, however, Cepheid variables are known to be single, pulsating stars.

Much of Duncan's later work was conducted at Mount Wilson Observatory, which he first visited in 1920/1921, and thereafter as a voluntary researcher during his summers from 1922 to 1949. Duncan became a talented photographer, and many of his photographs of nebulae and galaxies were reproduced in astronomy textbooks from the 1920s through the 1950s. He wrote an introductory college textbook, *Astronomy* (first edition, 1926), which passed through several editions. Duncan also published an abbreviated textbook, *Essentials of Astronomy* (first edition, 1942), and coauthored a laboratory manual. He developed a number of teaching aids in the discipline.

By comparing photographic plates exposed at different epochs, Duncan discovered a rapid expansion of the filaments in the Crab Nebula, reminiscent of the growth of an envelope around Nova Persei in 1901. Duncan returned to this problem in 1938 and demonstrated that further expansion had taken place. We now understand these filaments to be the remains of a supernova, or exploding star, which was witnessed by Asian astronomers in the year 1054.

Duncan also examined plates he had taken of the "spiral nebula" M33. While searching for novae, he discovered three faint variable stars in 1920. By mid-1922, Duncan had followed their variations on 17 plates but he neither determined whether they had fixed periods nor suggested that they might be Cepheids. His discovery of variable stars in "spiral nebulae," along with independent discoveries by **Max Wolf** and **Walter Baade** in Germany, prepared the way for **Edwin Hubble**'s discovery of a Cepheid variable star in the "spiral nebula" M31. Hubble thereupon established that the "spiral nebulae" were in fact distant galaxies that lay well beyond the confines of the Milky Way.

Duncan's long-exposure photographs, taken with the world's largest telescopes, contributed to scientific knowledge and the popularization of science. His textbook remained one of the best introductions to the subject for 30 years. Duncan's observations of the Crab Nebula and of M33 placed him on the cusp of major developments in our knowledge of supernovae and the study of external galaxies.

Duncan was elected a fellow of the Royal Astronomical Society and secretary of the American Astronomical Society (1936–1939). He was a member of the International Astronomical Union, American Association for the Advancement of Science, and numerous other professional organizations. His papers and letters may be found in the archives of Wellesley College, and at the observatories where he worked: Harvard, Lowell, Arizona, Lick, and Mount Wilson.

Rudi Paul Lindner

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Dunér, Nils Christoffer

Born **Billeberga near Helsingborg, Sweden, 21 May 1839**
Died **Stockholm, Sweden, 10 November 1914**

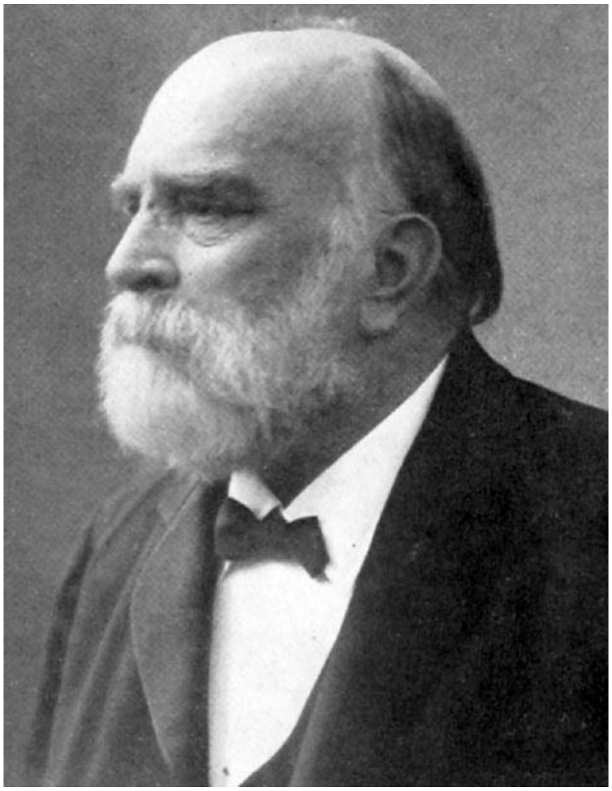
By substantially upgrading the Lund and Upsalla observatories, Nils Dunér placed Swedish astronomy on a modern footing with new equipment, improved observing practices, and introduced astrophysical techniques. Dunér was the eldest son of Vicar Dr. Nils Dunér and his wife Petronella (*née* Schlyter). Nils and his 18-month younger brother Gustav, who later became a physician, were raised in a well-educated family. They received their first lessons from their father, formerly a teacher at several schools in Schonen and principal at the high school in Billeberga. At the age of eight, Nils was able to read Latin texts and improved his knowledge of French later in school, learning so fast that he finished high school before reaching the age of 17.

As a student at the University of Lund, Dunér began studying mathematics and attended astronomy classes under professor John Mortimer Agardh. But it was Dr. Axel Möller, Agardh's assistant, who led and supported Nils Dunér in his studies. Dunér was so successful as a student that he worked as an assistant, first at the small university observatory and then at the Institute of Physics. He also participated in Otto Martin Torell's expeditions to Spitzbergen in 1861 and 1862 and the 1864 expedition led by Nils Adolf Erik Nordenskjöld that prepared the trigonometric survey of these islands.

In 1862, Dunér presented his doctoral thesis on the orbital elements of the minor planet (70) Panopaea. In the fall of the same year, he was promoted to assistant at the observatory. After Möller succeeded Agardh as professor and director of the observatory in 1864, Dunér was promoted to observer.

Dunér immediately acquired a new 4-in. Steinheil refractor for the observatory located atop the university library. Agardh had applied for some money to build a new observatory in the southern parts of Lund (today Svanegatan 9), which was approved in 1862. Möller, as Agardh's successor, supervised the construction of the new observatory, which was completed in 1867 with the installation of a new refractor with a 9.6-in. lens made by Merz in Munich. Dunér used the latter instrument for positional observations of comets and minor planets as well as micrometric observations of double stars. His catalog of 432 double stars was published in 1876. In 1877, Möller acquired a meridian instrument and initiated positional observations for the zone between 35° and 40°. These observations, begun in 1878 by Dr. Anders Lindstedt who later left for the observatory at Dorpat, were completed in 1882 by Dunér and Dr. Folke Engstöm, but the reduction of the data took several years. The results were not published until 1900 as part of the *Katalog der Astronomischen Gesellschaft* [AGK1].

In parallel to the zonal observations, Dunér turned his interest to the new field of astrophysics, in particular to spectroscopy. After 1878, Dunér undertook a spectroscopic survey, searching for red and orange stars matching **Angelo Secchi**'s class III stars (today's M-stars). He discovered more than 100 new candidates for this class. The results were published in a catalog of 352 stellar spectra in



1884. **George Hale** and **Ferdinand Ellerman** later commented on the difficulty of the visual observations that Dunér completed successfully in the prephotographic era of spectroscopy.

Dunér's interest in spectroscopic work did not fade, but the observatory's instruments limited his work to the brighter stars. In 1886, he acquired a Rowland grating, which formed the basis for a new spectroscope built by the Jürgensen Company of Copenhagen, a firm that made instruments for scientific, military, and industrial use. With this instrument Dunér determined the rotational period at different solar latitudes by measuring the Doppler shift of lines in the solar spectrum. His work confirmed and refined the rotational periods that had earlier been determined from sunspot observations by **Richard Carrington**. Dunér's work had the additional benefit, as Axel V. Nielsen observed, of quieting opposition to the reliability of Doppler effects as an astrophysical tool. In 1899, Dunér repeated several of these spectroscopic observations with a larger instrument in Uppsala, confirming, in particular, the solar rotation results first determined in Lund.

In 1888, Dunér was appointed professor of astronomy and director of the Uppsala Observatory. By 1893, he had acquired a new double refractor for Uppsala; the mechanics by Repsold were equipped with Steinheil objective lenses of 13 in. for the photographic objective and 14.2 in. for the visual objective. Unfortunately, both lenses were technically unsatisfactory, and although Steinheil undertook to correct the problems, the double refractor was not in full service observationally until September 1899. Probably due to his age and the loss of time with the refurbishment of the telescope, Dunér's activity decreased, but he continued to use this instrument for his observations of the Sun, work on double stars, and, together with **Östen Bergstrand**, engage in photographic astrometry of the minor planet (433) Eros in a campaign to determine the solar parallax. One of Dunér's important results from his tenure at Uppsala was his demonstration that observational anomalies associated with the eclipsing binary star Y Cygni could be accounted for by substituting elliptical orbits for circular orbits. Dunér proposed that the two mutually eclipsing stars were both revolving around a common center of gravity with a common line of apsides, rotating in the planes of the two orbits. On 1 April 1909, Nils Dunér retired from his post as director; his assistant for several years, Bergstrand, succeeded him.

Dunér was awarded four prizes by the Swedish Academy of Sciences, the Rumford medal by the Royal Society of London in 1892, and the Lalande Prize by the French Académie des sciences in 1887. In 1863, he was one of the founding members of the Astronomische Gesellschaft. In addition to his research work, Dunér was a member of the planning commission for the *Carte du Ciel* project, and also member of a Swedish committee for the trigonometric survey of Spitzbergen. Moreover, he was a bank director as well as a member of the town council in Uppsala.

During his long and fruitful life as an astronomer, Dunér never had observed a total eclipse of the Sun. In August 1914, he traveled to Norrland with a small instrument to observe the eclipse, but it was to be his last astronomical observation. Dunér moved to Stockholm, where it would be more convenient to discharge his duties to the local Free Masons assembly and avoid frequent travel. Unfortunately, he fell ill with pneumonia and died shortly after his arrival.

In 1874, Nils Dunér married Hilda Aurora Trägårdh, the daughter of Vicar Carl Trägårdh and his wife Henriette (*née* Nelander). They had four sons.

Christof A. Plicht

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Dungal of Saint Denis

Flourished **(France), 9th century**

When Charlemagne asked this monk about two eclipses occurring within 6 months of each other, Dungal did not know that his response to the emperor would become a primer in Carolingian astronomy.

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Dunham, Theodore, Jr.

Born **New York, New York, USA, 17 December 1897**
Died **Chocorua, New Hampshire, USA, 3 April 1984**

American physicist, astronomer, and physician Theodore Dunham, Jr. developed coudé spectrographs at Mount Wilson Observatory and at Mount Stromlo Observatory in Australia; introduced the Schmidt camera in spectroscopy; studied stellar atmospheres, interstellar material, and planetary atmospheres; identified CO_2 in the atmosphere of Venus; developed photoelectric detectors for spectroscopy; and applied physical methods to research in medicine and surgery.

Dunham's interest in astronomy began early. The son of Theodore Dunham, a surgeon, and Josephine Balestier Dunham, he prepared at Saint Bernard's School and the Browning School, New York City. As a teenager, Dunham submitted data to the American Association of Variable Star Observers, and by the age of 17 he had built an observatory on the grounds of his family's cottage in Northeast Harbor, Maine, where his father practiced medicine in the summers.

Theodore W. Richards, Nobel Laureate in Chemistry, was Dunham's advisor through his 4 years at Harvard College. In his senior year, Dunham worked full time in Richards' laboratory studying the potential of the zinc electrode. He and Richards were coauthors of Dunham's first paper. Dunham received an AB *summa cum laude* in 1921.

Dunham next turned to medicine, attending Harvard Medical School, transferring to Cornell University, and living at home in New York City. At Cornell University, he studied under Ewing, receiving an MD in 1925.

His passion for astronomy took Dunham to Princeton University, where he studied under **Henry N. Russell**. Russell brought back from Mount Wilson Observatory a film copy of a spectrum of α Persei, pulled it out of his left pocket, gave it to Dunham, and said, "Here's your thesis."

As a graduate student, on 21 June 1926, Dunham married Miriam Phillips Thompson, daughter of Mr. and Mrs. William G. Thompson of Boston. He received an AM and Ph.D. in physics in 1926 and 1927 from Princeton University.

With Russell's recommendation, in 1927 Dunham went to Mount Wilson Observatory with a National Research Council Fellowship. He was a staff member of Mount Wilson Observatory from 1928 to 1947. On his arrival, Dunham was struck with how he came with the approach of a physicist, while most of the remaining staff were top-notch observers. Russell's annual visits stimulated the research. Dunham was fired by the spirit of **George Hale** the missing force behind Mount Wilson.

In the summer of 1929, Dunham attended a symposium on astronomy and quantum physics at the University of Michigan, where he met **Arthur Milne** of Oxford and **Harry Plaskett**, both of whom became lifelong friends. The Milne daughters stayed with the Dunhams from 1940 to 1945.

In 1932, Dunham discovered that the atmosphere of Venus is principally composed of CO_2. At that time, astronomers tended to believe that the Earth and Venus had similar atmospheres, but Dunham (with **Walter Adams**) found some unusual features in the spectrum of Venus. Dunham demonstrated that if light were sent through a long pipe containing compressed CO_2, the same spectrum could be reproduced on the Earth, indicating that CO_2, under higher pressure than the Earth's atmosphere, had been observed in the atmosphere of Venus. **Arthur Adel** subsequently published a theoretical interpretation of the CO_2 spectrum that validated these experimental results. Dunham's conclusion was dramatically confirmed 35 years later in measurements transmitted from US and Soviet spacecraft. Another of Dunham's planetary contributions was the confirmation of the presence of methane and ammonia in Jupiter.

While Dunham was at Mount Wilson Observatory, Russell tried to bring him back to Princeton University to groom him as a successor. Adams was also interested in Dunham as his own successor at Mount Wilson Observatory. In April 1934, Russell proposed to Adams that Dunham be shared in a joint appointment between Mount Wilson Observatory and Princeton University. By 1935, out of loyalty to Russell, Dunham accepted a 3-year appointment as a part-time associate professor at PrincetonUniversity, where he lectured in 1935 and 1936, but Dunham ultimately decided to remain at Mount Wilson.

His wife's brother, Charles G. Thompson, and sister-in-law, Alice Bemis Thompson, heard from Dunham about the shortage of funding at Mount Wilson Observatory for equipment to use with its good telescope. In 1936, Mr. and Mrs. Thompson founded the Fund for Astrophysical Research, Inc. [FAR], with a small gift that allowed it to support the purchase of such equipment. Dunham was the FAR's scientific director from its founding until his death. The FAR's first project was the figuring of a 36-in. spherical mirror for the Mount Wilson coudé spectrograph.

Before the United States entered World War II, Dunham traveled to England to advise on optical instruments as a member, from 1940 to 1942, of the Section on Instruments of the Office of Scientific Research and Development [OSRD]. From 1942 to 1946, he was chief of the Optical Instrument Section (16.1) of the OSRD, under George Harrison and Vannevar Bush.

After the war, Dunham's interest in medicine continued. He wanted to work on some ideas on the spectroscopy of cells in his spare time, using a laboratory that his friend Linus Pauling could assist in making available at CalTech. The Carnegie Institution, which operated Mount Wilson, appeared to be taking a dim view of outside scientific activities, and in 1946, as he was leaving the OSRD payroll, Dunham resigned from his Mount Wilson position. Dunham then spent several years applying physical methods to medical research, first from 1946 to 1948 as a Warren Fellow in Surgery at Harvard Medical School and then from 1948 to 1957 at the School of Medicine and Dentistry and the Institute of Optics at the University of Rochester, where he developed instrumentation for spectrophotometric analysis of small regions of biological cells.

At the 1952 International Astronomical Union meeting in Rome, **Richard van der Riet Woolley,** Jr., asked Dunham to come down to Canberra to build a spectrograph for Mount Stromlo Observatory. Five years later, Dunham joined the faculty of the Australian National University, where he designed and installed a spectrograph at the Mount Stromlo Observatory for use with its 74-in. telescope in studying the composition of the stars of the Southern

Hemisphere. From 1965 to 1970, Dunham was a senior research fellow at the University of Tasmania, Australia.

After returning to the United States in 1970, Dunham resumed his earlier association with the Harvard College Observatory. Until his death, he continued to encourage the development of a spectrographic observatory at the University of Tasmania.

Dunham was survived by his wife and children, Theodore Dunham, III, and Mary Huntington Dunham. At the time of his death, he had just completed designing and supervising the construction of a 0.3-m computer-guided telescope of a new alt-azimuth design. It was installed and dedicated in his memory at the new Science Center of the University of Chicago in 1985. The FAR then augmented its small endowment by selling its scientific equipment and began a program of making annual small grants known as the Theodore Dunham, Jr. Grants in Astronomy and Astrophysics.

Dunham was the author of more than 50 scientific articles and a member of many scientific organizations, including the American Physical Society, the Royal Astronomical Society, the American Astronomical Society, the American Association of Variable Star Observers, the Astronomical Society of the Pacific, the American Optical Society, the New York Academy of Sciences, and the International Astronomical Union (in which he was a member of commissions on instruments, stellar spectra, and interstellar material).

Wolcott B. Dunham Jr.

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Dunthorne, Richard

Born **Ramsey, Huntingdonshire, England, 1711**
Died **Cambridge, England, 10 March 1775**

Richard Dunthorne was an observer, mathematical astronomer, and surveyor. Dunthorne's father was a gardener who sent his son to the free grammar school at Ramsey. Here he was noticed by Roger Long, master of Pembroke Hall, Cambridge, who employed Richard as a footboy in return for a mathematical education.

Dunthorne taught at a Cambridge University preparatory school in Coggeshall, Essex, before returning to Cambridge in the 1750s as butler and astronomical observer to Pembroke Hall. He held the post for the rest of his life. He was also scientific assistant to Long until Long's death in 1770. In addition, Dunthorne was superintendent of the Bedford Level Corporation, for which he conducted a survey of the fens and was responsible for lock building and drainage work. From 1765 to his death, Dunthorne was a comparer for the *Nautical Almanac*.

Despite never formally graduating from Cambridge University or holding an academic post, Dunthorne made several contributions to mathematical astronomy. In 1739 he published *The Practical Astronomy of the Moon, or New Tables of the Moon's Motion*. The tables were based on **Isaac Newton**'s lunar theory, and Dunthorne went on to use the tables to compare lunar longitudes computed from his tables with longitudes obtained by observation. He published the results in the *Philosophical Transactions of the Royal Society* in 1747. When **Tobias Mayer** was awarded £3,000 in 1765 for his work on the motion of the Moon, Dunthorne wrote to the Board of Longitude pointing out that he had published similar ideas some years before, but the board declined to reward him.

Dunthorne continued to study the Moon, publishing a letter in 1749 giving a figure for the acceleration of the Moon's mean motion that he had calculated using eclipse data going back 2,000 years. He also made contributions concerning comets and developed plans for new tables of the motions of Jupiter's satellites.

In 1765, **Nevil Maskelyne** appointed Dunthorne as the first comparer of the *Nautical Almanac*. Dunthorne was responsible for checking the work of the computers calculating the ephemerides and for selecting stars for the computation of lunar distances. In the same year, Dunthorne planned and funded the building of an observatory on the Shrewsbury Gate of Saint John's College, Cambridge; he also donated the instruments necessary to fully equip the observatory. From here Dunthorne observed the 1761 and 1769 transits of Venus.

Mary Croarken

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Dürer, Albrecht

Born **Nuremberg, (Germany), 21 May 1471**
Died **Nuremberg, (Germany), 6 April 1528**

German artist Albrecht Dürer is often credited with the first published star map. The 1515 woodcuts, printed in Vienna, accompanied text written by **Johann Stabius**. The imaginative constellation figures Dürer created were frequently copied. His famous engraving, *Melancolia I* (1514), uses a bright comet as its primary symbol.

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Dymond, Joseph

Born **Brierly, (South Yorkshire), England, 5 December 1746**
Died **Blyth, Northumberland, 10 December 1796**

With **William Wales**, Joseph Dymond initiated Western astronomical research from Canada. The two established the latitude of Fort Churchill (Hudson's Bay) in 1768, preparatory to the transit of Venus, successfully observed the following year.

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Dyson, Frank Watson

Born **Measham near Ashby-de-la Zouch, Leicestershire, England, 8 January 1868**
Died **at sea near Cape Town, South Africa, 25 May 1939**

Frank Dyson, a highly successful director of the Royal Observatory at Greenwich, contributed significantly to the study of proper motions of stars, and inaugurated the transmission of time *via* radio, but he is best known for helping to organize the 1919 solar eclipse expedition which provided the first detection of gravitational deflection of starlight.

The oldest of seven children of a Baptist Minister, Dyson won a national mathematics contest at 13. This led eventually to scholarships to the University of Cambridge, where he was an honors student in mathematics and astronomy. He continued at Cambridge University as a fellow, achieving some renown for calculating the gravitational potential of an anchor ring. Dyson was appointed chief assistant to Astronomer Royal **William Christie** at the Royal Observatory, Greenwich, in 1894.

Although he knew nothing of instruments or observation when appointed, Dyson successfully supervised the compilation of the Greenwich portion of the *Carte du Ciel* and *Astrographic Catalogue*. Many *Carte du Ciel* plates had already been made by his predecessor, **Herbert Turner**. Dyson improved the reduction of the measurements, instituting new determinations of the locations of the reference stars on the plates.

Dyson rereduced visual measurements of circumpolar stars made by English amateur **Stephen Groombridge** some 80 years earlier, greatly increasing the precision of the stars' positions. Then, with **William Thackeray**, Dyson determined the proper motions of 4,239 stars near the North Celestial Pole. Analysis of these motions led to improved values for the rate of the Earth's precession and for the solar motion. Dyson and Thackeray found that the motions of the stars were related to their magnitudes and galactic latitudes. They found that the fastest-moving stars moved in two streams, as had been suggested by **Jacobus Kapteyn**, but their measurements lent more support to **Karl Schwarzschild**'s ellipsoidal model for stellar motions.

After viewing six eclipses, with good weather every time, Dyson called himself "a hundred percent eclipse observer." In Sumatra in 1901 he obtained spectra of the solar chromosphere and corona, including the first detection of the element europium in the Sun. In 1905, Dyson published wavelengths and intensities of 1,200 emission lines he had photographed in the spectrum of the chromosphere on three expeditions.

Dyson served as Astronomer Royal for Scotland from 1905 to 1910. Having been the first to complete his observatory's portion of the *Carte du Ciel* at Greenwich, he now agreed to measure and reduce plates made at Perth, Australia. Dyson also began a study of double stars too close to the North Celestial Pole to be reached by the Greenwich refractor, a project that continued long after he left Edinburgh. Dyson was a popular professor at the University of Edinburgh; his lectures on introductory astronomy became his first book.

In 1910, on returning from the meeting of the International Solar Union in Pasadena, Dyson was appointed the ninth Astronomer Royal, a position that then included the directorship of the Royal Observatory at Greenwich.

The Royal Observatory had been providing time service by telegraph since the 19th century. In 1924, Dyson began sending time signals directly to the British Broadcasting Company for broadcast throughout the country. The famous "six pips" were broadcast at 1 s intervals, with the last one on the hour. Dyson adopted the new, precise "master-slave" clock invented by William Hamilton Shortt, what had first been demonstrated at the observatory in Edinburgh in 1921.

During World War I, Dyson lost 36 members of his staff to the armed forces, and data reduction fell behind, even though he hired retirees, conscientious objectors, Belgian refugees, and women in their place.

In the middle of the war, in the capital of Britain's enemy, **Albert Einstein** published the general theory of relativity. Einstein predicted, among other things, that starlight passing the limb of the Sun would be deflected by about 1.75″, an effect that might be measurable on photographs of star fields surrounding the Sun during a total eclipse. **Arthur Eddington**, Dyson's former chief assistant at Greenwich and now a Cambridge professor, received the journals *via* neutral the Netherlands and publicized the new theory in England.

Meanwhile, Eddington's colleagues were anxious to get him a deferment from the military draft, as the Quaker professor wanted to declare himself a conscientious objector, and they believed such a declaration would embarrass the university. Dyson pointed out that the solar eclipse of 29 May 1919 would occur when the Sun was in the midst of the Hyades, offering no fewer than 13 stars close enough to the Sun's limb and bright enough to photograph. It would be the best eclipse in 1,000 years for measuring the Einstein effect.

Dyson persuaded the Admiralty to let him plan one expedition and to defer Eddington to plan another. As **James Jeans** described it:

> In 1918, in the darkest days of the war, two expeditions were planned, one by Greenwich Observatory and one by Cambridge, to observe, if the state of civilization should permit when the time came, the eclipse of May 1919 with a view to a crucial test of Einstein's generalized relativity.

> The Armistice was signed in November 1918; the expeditions went and returned, bringing back news which changed, and that irrevocably, the astronomer's conception of the nature of gravitation and the ordinary man's conception of the nature of the universe in which he lives.

Dyson was awarded the Catherine Wolfe Bruce Gold Medal of the Astronomical Society of the Pacific in 1922 and the Gold Medal of the Royal Astronomical Society and the Royal Medal of the Royal Society, both in 1925. He held every office in the Royal Astronomical Society, and served as president of the International Astronomical Union from 1928 to 1932. Dyson retired at 65 and spent his last years advising scientific organizations, coauthoring a book on eclipses, and visiting his eight children and numerous grandchildren.

Dyson's papers are in the Royal Greenwich Observatory archives at Cambridge University.

Joseph S. Tenn

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Dziewulski, Wladyslaw

Born **Warsaw, Poland, 2 September 1878**
Died **Torun, Poland, 6 February 1962**

Wladyslaw Dziewulski investigated celestial mechanics, stellar kinematics, and Cepheid variable stars, and directed two observatories in his native land. He graduated from high school in Warsaw. Between the years 1897 and 1901, Dziewulski studied astronomy and majored in mathematics and physics at Warsaw University. He continued his astronomical studies under **Karl Schwarzschild**'s guidance at Göttingen University (1902–1903 and 1907–1908). He was awarded his Ph.D. at Jagiellonian University (Cracow) in 1906, for investigations of the secular perturbations on minor planet (433) Eros.

Between 1903–1906 and 1908–1909, Dziewulski was an assistant at the Jagiellonian University Observatory. In 1909, he became an adjunct faculty member and a lecturer at the university (1916). In 1919, Dziewulski was appointed professor of astronomy at the Stefan Batory University in Vilnius, where he worked until the outbreak of World War II. In 1921, he built the first pavilion of the new observatory at Vilnius, where a Zeiss refractor was installed. Other purchases included an astrograph and a reflector equipped with a spectrograph. Dziewulski served as the observatory director and briefly as chancellor (1924/1925).

In 1945, Dziewulski and other officials established the new Nicholas Copernicus University at Torun. There, he directed its observatory and was appointed vice chancellor before retiring as professor emeritus in 1960.

Dziewulski's doctoral thesis, "Perturbation of Mars in the Movement of Eros," was the first such work to consider the influence of Mars, whereas before only perturbations caused by the jovian planets were considered. For many years, Dziewulski's studies of the movement of minor planet (153) Hilda were regarded as a model. He likewise investigated the orbits of such minor planets as (13) Egeria, (133) Cyrene, (887) Alinda, and (1474) Beira.

During his stay in Göttingen, Dziewulski worked under Schwarzschild's direction to produce a catalog of the photographic brightnesses of some 3,500 stars (the *Göttinger Aktinometrie*). Another large photometric work measured the brightnesses of stars near the North Celestial Pole. It became a standard reference that was used by many subsequent astronomers.

Dziewulski was also absorbed by stellar kinematics. He calculated the direction of movement of the Sun (the solar apex) and the movements of other nearby stars. In 1916, he devised an original method to calculate the vertices of movement of peculiar groups of stars.

At both Vilnius and Torun, Dziewulski systematically observed variable stars. In particular, he investigated the colors of Cepheid variables. From the corresponding temperature changes inferred in these stars, he offered an independent confirmation of the pulsation hypothesis.

While in Torun, Dziewulski was a key organizer of the astronomical observatory at Piwnice. A Draper astrograph became its first instrument. After Dziewulski's death, a 60-cm Schmidt camera was installed at Piwnice.

Dziewulski was a member of the Polish Academy of Sciences, the British Astronomical Association, and the International Astronomical Union. In 1961, he was awarded an honorary doctorate from the Nicholas Copernicus University. A crater on the Moon has been named for him.

Stanislaw Rokita

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E

Ealhwine

➤ **Alcuin**

Easton, Cornelis

Born **Dordrecht, the Netherlands, 10 September 1864**
Died **The Hague, the Netherlands, 3 June 1929**

Dutch journalist and amateur astronomer Cornelis Easton published what seems to have been the first suggestion for the spiral structure of the Milky Way galaxy that put the center of the spiral well away from the Solar System. He was the son of J. J. Easton, a sailor, and M. W. Ridderhof and graduated from high school in 1881, next undertaking a course of instruction for people entering into government in the Dutch East Indies. Easton continued at the Sorbonne University, Paris, studying French until 1886, and after a short period of teaching, he began a career as a journalist in association with the leading Dutch newspapers *Nieuwe Rotterdamsche Courant* (1895–1906), *Nieuws van den Dag* (1906–1923), and *Haagsche Post* (from 1923).

Easton was already an enthusiastic amateur astronomer in his high-school years, and he soon gained fame by his careful drawings of the brightness distribution of the Milky Way. These were published under the title *La Voie Lactée dans l'hemispère boréal* in Paris in 1893. He worked in close association with the famous astronomer **Jacobus Kapteyn** of the University of Groningen, the Netherlands, who highly appreciated his work, in fact so much that in 1903 the university granted Easton an honorary degree in physical sciences.

Easton's best-known drawing appeared in 1900 and showed a face-on view of a circular Milky Way, with the Solar System at the center of the circle, but the center of a distorted and complex system of spiral arms a considerable distance away. His next step was to incorporate star counts derived from the existing survey of the sky, the *Bonner Durchmusterung*, into the hypothetical structure of the galaxy. The direction of the center in this 1913 model and its structure were not confirmed by later investigations.

Besides working in astronomy, Easton was active in various other fields of science, in particular climatology. In 1923, he became a member of the board of the Netherlands Meteorological Institute, and in 1928 he published an impressive statistical–historical study of the climatological conditions in Western Europe, under the title *Les hivers dans l'Europe occidentale*.

Adriaan Blaauw

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Eckert, Wallace John

Born **Pittsburgh, Pennsylvania, USA, 19 June 1902**
Died **Englewood, New Jersey, USA, 24 August 1971**

American celestial mechanician Wallace Eckert pioneered the application of punch-card computing machines to problems of astronomical orbit determinations. He was the son of farmers John and Anna (*Née* Heil) Eckert, and received degrees from Oberlin College (AB: 1925), Amherst College (AM: 1926), and Yale University (Ph.D. in astronomy: 1931, with a thesis on the orbit of Trojan-type minor planet (624) Hektor, completed under **Ernest Brown**). From 1926 to 1940 Eckert served on the astronomy department faculty of Columbia University, rising to the level of professor of celestial mechanics. He spent his last two professional years, 1968–1969, at Yale University, and throughout his career was particularly generous in providing computational facilities for the astronomers at Yale University working on planetary, asteroid, and satellite orbits.

In 1933, Eckert worked on developing a punch-card accounting machine for astronomical calculations at the automatic scientific computing laboratory at Colombia University. The laboratory became the Thomas J. Watson Astronomical Computing Bureau in 1937 as a joint project between the university and International Business Machine Corporation [IBM]. The Watson Laboratory led the way in developing large-scale computers for use in World War II.

In 1940, Eckert became the director of the Nautical Almanac Office of the United States Naval Observatory and served in that capacity until the end of World War II. He published his book *Punch Card Methods in Scientific Computation* in the same year. During the war, the Almanac Office used automatic calculation methods to develop celestial navigational charts and tables for use by the US Army and US Air Force. The first *Air Almanac* was published in 1940.

At the end of the war, Eckert left the Nautical Almanac Office to become the director of the Watson Scientific Computing Laboratory, a department of pure science at IBM. He held this position for 23 years. The laboratory served as a major computer research and training facility in all branches of science. Hundreds of scientists were trained in scientific computation there.

In early January 1948, Eckert and a team from IBM finished the Selective Sequence Electronic Calculator [SSEC], which is considered the first true electronic computer. On 27 January 1948, the SSEC became the first electronic computer to accomplish the difficult task of calculating the Moon's position. This hybrid machine was made of several systems of storage that included 12,500 vacuum tubes and 21,400 mechanical relays. Its memory section consisted of eight vacuum tubes, 150 words on a memory relay, and 66 loops of banded paper that could store 20,000 words of 20 digits each. This machine could read its instructions either from one of the paper loops or from memory.

In 1954, Eckert and his team completed the Naval Ordnance Research Calculator [NORC]. At the time of its construction, NORC was the most powerful computer in the world. Eckert used SSEC and NORC to compute precise planetary positions and refine the lunar theory. In 1951, he published his book *Coordinates of the Five Outer Planets*. This work consisted of precise orbital calculations for the planets Jupiter, Saturn, Uranus, Neptune, and Pluto.

In the late 1950s and early 1960s, Eckert worked on developing precise positions of the Moon based on the formulas developed by astronomer and mathematician Ernest Brown. Brown's formulas consisted of about 1,650 trigonometric terms, with many of them being variable coefficients. Eckert realized that using Brown's tables alone as a basis of improving the accuracy of knowing the Moon's position was no longer viable. He therefore developed a computer program to calculate the lunar position using Brown's formulas directly instead of relying on tables based on the formulas. In 1965, Eckert was able to determine that there must be a concentration of mass near the lunar surface that was causing slight variations in the Moon's orbital position. These mass concentrations (known as mascons) were later proven to exist when they caused fluctuations in the orbital elevation of a spacecraft in lunar orbit as the craft passed over the mascons. Eckert's lunar positions were accurate to within a few feet per century and included accounting for lunar oscillations as small as 1 inch.

In 1966, Eckert was awarded the James Craig Watson Medal of the National Academy of Sciences, and in 1968, he received an honorary doctorate of science from Oberlin College. Eckert retired from IBM in 1967 and from his professorship of celestial mechanics at Columbia in 1970.

Without the pioneering computer work done by Eckert, his staff, and students in determining the exact position of the Moon at any given time, the manned landings on the Moon might not have been possible by the end of the 1960s. A nearside lunar crater at 17°.3 N; 58°.3 E was named in 1973 by the International Astronomical Union to honor Wallace John Eckert, and minor planet (1750) Eckert was named for him.

Robert A. Garfinkle

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Ecphantus

Born **Syracuse, (Sicily, Italy), *circa* 440 BCE**

Ecphantus is said to have identified Pythagorean monads with corporeal atoms. However, so little is known of his life that some late 19th-century scholars doubted his existence. Both Hippolytus and **Aetius** record that he was a Syracusan and an atomist, so he must have lived when he could have been influenced by **Leucippus** and **Democritus**. Guthrie (1962, p. 325) hazards that Ecphantus "probably belonged to the last generation of Pythagoreans who were contemporaries of Plato."

In Ecphantus's version of atomism, atoms differ in size, shape, and force. They move not by random and mindless physical forces, but by divine providence. In Democritean atomism, infinitely many atoms have congregated into infinitely many worlds scattered throughout infinite space. In contrast, Ecphantus postulated a finite number of entities constituting a single spherical cosmos with a spherical Earth at its center.

Contrary to common belief, Ecphantus claimed that the Earth rotates in an easterly direction, while the sphere of fixed stars remains motionless. In *De Revolutionibus* **Nicolaus Copernicus** refers to Aetius's report of **Heraclides**' and Ecphantus's belief in terrestrial rotation as his inspiration for seriously considering the hypothesis that the Earth moves.

James Dye

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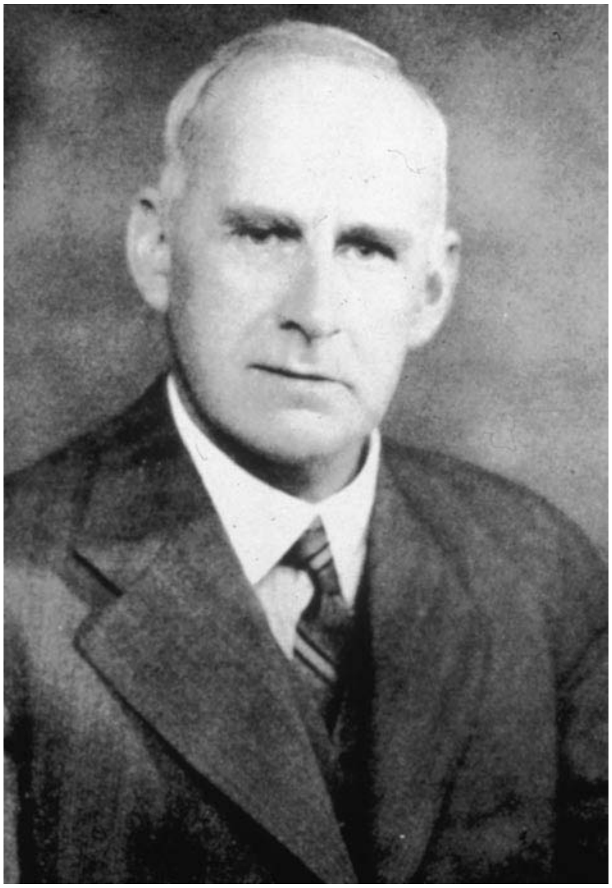
Eddington, Arthur Stanley

Born **Kendal, (Cumbria), England, 28 December 1882**
Died **Cambridge, England, 22 November 1944**



English theoretical astrophysicist Arthur Stanley Eddington is most widely remembered for coordinating the 1919 solar eclipse expeditions that provided confirming evidence for the gravitational deflection of light predicted by **Albert Einstein**'s general theory of relativity. He also formulated the modern theory of Cepheid and other pulsationally varying stars, wrote down the equations that describe how radiation moves through stellar material, and was a pioneer in attributing stellar energy sources to "subatomic" (nuclear) processes and in recognizing that interstellar gas pervades the Milky Way Galaxy.

Eddington was born to Sarah Ann Shout Eddington and Arthur Henry Eddington, a Quaker schoolmaster and the descendent of four generations of Somerset Quakers. After his father's early death, Arthur Stanley was educated at home and in small schools in Weston. His love of and talent for mathematics was soon evident, and he won many contests and prizes. At the age of 16 he won a scholarship to Owens College, Manchester, where he studied physics and math with **Arthur Schuster** and Horace Lamb. At Manchester, Eddington lived at Dalton Hall, where he came under the lasting influence of the Quaker mathematician J. W. Graham.

Eddington was always dependent on financial support, and a Natural Sciences Scholarship allowed him to enter Trinity College, Cambridge, in 1902. There he was coached by the famous mathematician **Robert Herman**, and became the first second-year student to earn a place as senior wrangler on the tripos. He received his BA from Cambridge in 1905, and his MA in 1909. After teaching briefly at Trinity College, Eddington went on to become chief assistant at the Royal Observatory, Greenwich, from 1906 to 1913. In 1913, he was appointed to a fellowship at Trinity College, Cambridge, and awarded the Plumian Professorship of Astronomy and Experimental Philosophy and the directorship of the Cambridge Observatory, positions that he held until his death. The best known of Eddington's students there were theoretical astrophysicist **Subrahmanyan Chandrasekhar** and historian and philosopher Clive Kilmister. He advised **Cecilia Payne-Gaposchkin**, who had been a Cambridge undergraduate, to pursue graduate studies in the United States.

Eddington's early work concerned the motions of stars through space, based primarily on proper motion data. His 1914 book, *Stellar Movements and the Structure of the Universe*, placed the Sun very near the center of the stellar system (then called the Universe, now called the Galaxy) and endorsed the two-stream hypothesis of **Jacobus Kapteyn**, in which the motions were described by two intermingling streams of stars moving in different directions relative to the Sun. The description given by **Karl Schwarzschild** in terms of velocity ellipsoids turned out to be more useful. Both were incomplete descriptions of the effects of a differentially rotating galactic disk, a nonrotating halo, and a solar position far from the center.

In Cambridge, Eddington turned his attention to the interior structure of stars, how energy was transported from the center to the photosphere, and what the sources of that energy might be. **Robert Emden** had formulated the mathematics of stars in which energy was carried by convection, and Schwarzschild had begun considering the effects of radiation shortly before his death in 1916. Eddington's standard model, begun in 1916, was a completely radiative star, and he concluded that the most common kind of stars, like the Sun, were the ones where the pressure due to the hot gas and the pressure due to radiation were equal. He, like most contemporaries thought that stellar composition must be similar to that of the Earth, with lots of silicon, oxygen, and iron.

During this period, Eddington (1) correctly described the variable brightness of Cepheids as being due to inward and outward pulsation of the stars, driven by ionization and recombination of gas just under their visible surfaces; (2) coined the term "main sequence" to describe the locus of the majority of stars in a Hertzsprung–Russell diagram and the word "bolometry" to describe measuring the brightness of stars at all wavelengths; (3) derived for the first time the relationship between luminosity and mass ($L \propto M^3$) for fully radiative stars, which agrees with observations and does not depend on the nature of the energy sources; (4) endorsed the suggestion from **James Jeans**, with whom he otherwise had rather little in common, that the gas in stars would be completely ionized, so that perhaps the atoms could be crammed together much closer than they are on Earth; and (5) suggested an approximation to the structure of stellar atmospheres (the Milne–Eddington approximation) in which the particles that produce the continuum ("rainbow") and those that produce the absorption lines are completely mixed. The opposite, with the absorption layer on top, is the Schuster–Schwarzschild approximation, due to his former teacher and German contemporary.

During World War I Eddington became embroiled in controversy within the British astronomical and scientific communities. Many astronomers, chief among them **Herbert Turner**, argued that scientific relations with all of the Central Powers should be permanently ended due to their conduct in the war. Eddington, a Quaker pacifist, struggled to keep wartime bitterness out of astronomy. He repeatedly called for British scientists to preserve their prewar friendships and collegiality with German scientists. Eddington's pacifism caused severe difficulties during the war, especially when he was called up for conscription in 1918. He claimed conscientious objector status, a position recognized by the law, if somewhat despised by the public. However, the conscription board refused to grant such status since he had previously held a deferment for his astronomical work; the government would not allow him to be both a scientist and a Quaker. Only the timely intervention of the Astronomer Royal and other high-profile figures kept Eddington out of prison.

During the war Eddington was Secretary of the Royal Astronomical Society [RAS], which meant he was the first to receive a series of letters and papers from **Wilhelm de Sitter** regarding Einstein's theory of general relativity. Eddington was fortunate, being one of the few scientists able to understand the mathematics of relativity, and also one of the few interested in pursuing a theory developed by a German physicist. He quickly became the chief supporter and expositor of relativity in Britain. Eddington and Astronomer Royal **Frank Dyson** (one of the few other internationalists in the RAS) organized the 1919 expedition to make the first empirical test of Einstein's theory: the measurement of the deflection of light by the Sun's gravitational field. In fact, it was Dyson's argument for the indispensability of Eddington's expertise in this test that allowed him to escape incarceration during the war.

The eclipse expedition to Principe in Africa and Sobral in Brazil was held up as a complete success, and Eddington embarked on a campaign to popularize relativity and the expedition as landmarks both in scientific development and in international scientific relations. In recent years Eddington has been accused of having manipulated the data from the expedition to favor Einstein, but there is no evidence that this was the case. During the 1920s and 1930s Eddington gave innumerable lectures, interviews, and radio broadcasts on relativity (in addition to his textbook *Mathematical Theory of Relativity*), and later, on quantum mechanics. Many of these were gathered into books, including *Nature of the Physical World* and *New Pathways in Science*. They were immensely popular with the public, not only because of Eddington's clear exposition, but also for his willingness to discuss the philosophical and religious implications of the new physics. He argued for a deeply rooted philosophical harmony between scientific investigation and religious mysticism, and also that the positivist nature of modern physics (*i. e.*, relativity and quantum physics) provided new room for personal religious experience. Unlike many other spiritual scientists, Eddington rejected the idea that science could provide proof of religious propositions. His popular writings made him, quite literally, a household name in Great Britain between the world wars.

In addition to receiving popular acclaim, Eddington also received most of the traditional professional accolades, including more than a dozen honorary doctorates, memberships and medals of the Royal Society (London), the RAS (which he served as president and which later named one of its medals for him), the United States National Academy of Sciences, and the Astronomical Society of the Pacific.

By the time of the 1926 publication of his *Internal Constitution of the Stars*, Eddington had taken definite stands on a number of other issues. One was the basic source of stellar energy, which he attributed to processes concentrated at the centers of stars that would change one element into another. This allows for stellar lifetimes much longer than the gravitational contraction timescale of **William Thomson** and **Hermann Helmholtz** but much shorter than the 10^{12}–10^{13} years advocated by Jeans on dynamical grounds, which would have required the complete annihilation of stellar matter. He also applied general relativity to white dwarf stars, predicting that they should display a gravitational redshift (reported the next year, 1925, by **Walter Adams**). On the other hand, Eddington accepted **Ralph Fowler**'s 1926 suggestion that white dwarfs would be fully degenerate, but rejected the later conclusion of his student Chandrasekhar that there was an upper limit to the possible masses of these stars. Eddington's dispute with Chandrasekhar was not based on racism, as is sometimes claimed, but rather on straightforward disagreements about how to best combine relativity with quantum mechanics.

Eddington was also involved in applying general relativity to expanding universe models. He supported **Georges Lematre**'s 1927 work, but rejected the idea of a discontinuous "Big Bang" beginning to the Universe. His own work in cosmology focused on the role of the cosmological constant, which most scientists had rejected as superflows.

From about 1900 to 1930, the astronomical community was divided over whether diffuse material was pervasive in interstellar space, whether it might absorb significant amounts of light, and whether accretion from diffuse material might significantly augment the masses and brightnesses of stars. Eddington correctly interpreted observations by **John Plaskett** as meaning that at least calcium and sodium were pervasive, although he did not think such material would result in significant absorption or accretion.

Toward the end of his life, Eddington attempted his own unification of general relativity and quantum mechanics in the posthumously published *Fundamental Theory*. He provided what were intended as calculations from first principles of the total number of particles in the observable universe, of the fine structure constant of atomic physics, and other basic properties of nature. Few of his colleagues attempted, or were able, to follow the arguments, some of which were heavily philosophical.

Matthew Stanley and Virginia Trimble

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Edlén, Bengt

Born **Ringarum, Östergötland, Sweden, 2 November 1906**
Died **Lund, Sweden, 10 February 1993**

Swedish spectroscopist Bengt Edlén solved a 70-year-old puzzle by identifying emission lines in the solar corona (discovered in 1869 by **Thomas Young**) with transitions in very highly ionized atoms, thereby demonstrating that the corona is much hotter than the visible surface of the Sun. He received his secondary education in Norrköping, Sweden, and entered the University of Uppsala in 1926, earning a series of degrees ending with a doctorate in 1934.

By 1925, optical spectroscopy had reached a shortest wavelength of 155 Å, while X-ray spectroscopy had reached a longest wavelength of 17 Å. Karl M. G. ("Manne") Siegbahn of Uppsala, who had received the 1924 Nobel Prize in Physics for his work on X-ray spectroscopy, suggested that Edlén should try to fill in the gap. This led to a doctoral thesis on the ultraviolet spectra of light elements from lithium to oxygen, with wavelength measurements and identifications of energy levels extending up to carbon and nitrogen with four electrons removed and oxygen with five electrons missing. This early work led to the 1932 identification of emission lines of ionized carbon, nitrogen, and oxygen in Wolf–Rayet stars, whose spectra had been something of a mystery since their discovery in the 19th century.

After obtaining his degree, Edlén remained at Uppsala as a docent, finally being appointed to the professorship of physics at the University of Lund in 1944, a chair previously held by spectroscopists **Anders Ångström** and **Johannes Rydberg**. Edlén continued to work on atomic spectra, focusing on the similarities of atoms that have the same numbers of electrons, following ionization. (For instance, singly ionized magnesium is like sodium, and singly ionized argon like chlorine.) He took a suggestion from **Walter Grotrian** to follow such sequences right on up to very highly ionized atoms of argon, calcium, iron, and nickel, allowing him to predict the wavelengths that these atoms should emit or absorb. A very important result was that a line at 5303 Å would be produced by iron deprived of 13 electrons. This wavelength corresponded to a green emission feature seen in the spectrum of the solar corona during eclipses since 1869 and sometimes attributed to a nonexistent new element called "coronium." In 1942, Edlén identified this and a number of other coronal lines. Because of wartime barriers to trans-Atlantic communication, the news first reached the United States the following year in a paper written by Belgian astronomer **Polydore Swings**.

At Lund, Edlén established a large group of spectroscopists to work on other elements in other ionization states. The lines they predicted very often turned out to occur in the spectra of stars, gaseous nebulae, and even quasars, and the identifications made it possible to use these lines to determine the compositions and temperatures of the astronomical objects. Other features, like a pair of lines due to carbon missing three electrons, proved to be signatures of hot gas flowing away from stars in massive winds. The beginning of ultraviolet astronomy from satellites in the 1970s revealed many more of Edlén's lines, just as he was reaching emeritus status in 1973. Nonetheless, he continued to be an active member of the community for a number of years beyond retirement.

Among the honors Edlén received for his work were medals and prizes from the Royal Astronomical Society, the Optical Society of America, and the United States National Academy of Sciences.

Roy H. Garstang

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Eichstad, Lorenz

Born **Stettin (Szczecin, Poland), 1596**
Died **Danzig (Gdańsk, Poland), 1660**

Laurentius Eichstadius was an astrologer and ephemeris writer. Only a little is known about the life of Eichstadius. In his works, he declared himself to be not only a doctor of medicine, an ordinary civic health officer in the city of Szczecin in Pomerania (then German), but also an *Iatro Physicus*, a doctor involved in astrology. For an unknown length of time, Eichstad was professor of medicine and mathematics in Danzig.

Eichstad's initial shorter writings began to appear in 1622 and involved astrological subjects: the great conjunctions between Jupiter and Saturn along with their astrological consequences, astrometeorological forecasts for 1630 to 1633, and a defense of astrology against the reproach of being a form of forbidden magic, an issue that was frequently discussed at the time. If these brief works had not stood out from the published masses of astrological material, Eichstad's ephemerides would have obtained more prominence and even enjoyed widespread popularity. The tables appeared in three volumes: Vol. 1 for 1636–1640, Vol. 2 for 1641–1650, and Vol. 3 for 1651–1665. For each day of the respective years, they indicated the position of the Sun, the Moon, and the planets; the time of their rising and setting; the phase of the Moon; *etc*. In addition, the calculations of the Sun, Moon, and their eclipses were based on **Tycho Brahe**'s planetary theory as revised by **Christian Severin** (Longomontanus; *Astronomia Danica*, 1622), while the calculations for the planets were grounded in the *Rudolphine Tables* of **Johannes Kepler**. Ephemerides were of great importance because they were used to cast horoscopes and to construct the popular astronomical–astrological calendars.

In the first volume, Eichstad dealt with the history of ephemerides beginning with **Johann Müller** (Regiomontanus), provided several examples of the uses of an ephemeris, and included star catalogs for 1600 and 1700, formulated according to Brahe's precession constant of 51″/year, as well as a record of the rising and setting of stars on the latitude of Szczecin (53° 30′ N). The second volume contains, after an explanation of logarithmic calculations, a number of logarithmic tables based on the one composed by **John Napier**. In the third volume, 100 aphorisms about astrology are stated.

The tables upon which ephemeris calculations were based (rising of the signs of the zodiac, conversion tables for the sexagesimal systems, tables of the Sun's motion, precession, the precise rising of each degree of the zodiac, and tables for calculating the Moon's movement and deviant movement) were published by Eichstad in 1644 as *Tabulae harmonicae coelestium motuum.*

Jürgen Hamel

Alternate name

Laurentius Eichstadius

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Eichstad, Lorenz (1634–1644) : Pars prima ephemeridum novarum coelestium [et pars altera et tertia, for 1636–1660]. Stettin: Rhete

Eimmart, Georg Christoph

Born **Regensburg, (Bavaria, Germany), 22 August 1638**
Died **Nuremberg, (Germany), 5 January 1705**

Georg Eimmart was an observational astronomer, instrument-maker, and copper engraver. He was the son of George Christoph Eimmart, a painter and copper engraver, and Christiana Bauss. Eimmart was first apprenticed to his father as a painter and then trained in copper engraving and etching with Joachim Sandrart. From 1654 he studied mathematics, astronomy, and jurisprudence at the University of Jena. Following the death of his father in 1658, Eimmart returned to Regensburg, then proceeded to Nuremberg in 1660, where he became codirector, alongside Sandrart, of the Nuremberg School of Painting from 1674, and sole director from 1699 to 1704. Eimmart worked mainly as copper engraver and etcher, but was not so prominent as a painter.

Eimmart married Anna Walther in 1668. Their daughter, Maria Klara, later married professor Johann Heinrich Müller in Altdorf in 1706 and died during childbirth in the following year.

In 1677 Eimmart established a private observatory near the castle in Nuremberg. Its operation was interrupted in 1688 by the threat of war with France. In 1691 the observatory was reestablished, and continued to function until 1757. Eimmart instructed many young people in observation. His daughter Maria Klara supported him in his astronomical work. She produced 250 drawings of the phases of the Moon as well as the work *Iconographia nova contemplacionum de Sole*.

Eimmart was both builder and developer of various astronomical measuring-instruments, above all devices for measuring angles (sextants, quadrants, *etc.*). He used astronomical clocks and developed a helioscope. Eimmart commissioned, for example, from the Nuremberg mechanic Johann Ludtring a planetarium (orrery) with a diameter of approximately half a meter to demonstrate the workings of the Copernican system. On the pylons of the observatory alongside the instruments for measuring angles were also telescopes.

From 1678 Eimmart observed and investigated the zodiacal light. In 1679 he determined the local magnetic declination. Through a pendulum experiment he was able to derive a proof of the rotation of the Earth. Detailed observations remain of eclipses, comets, and the Moon. Simultaneously with **Christiaan Huygens**, Eimmart established the diurnal period of the refraction of starlight through the Earth's atmosphere. In 1694 he produced a map of the Moon that was published in Johann Zahn's *Specula Physico-mathematico-historica*. Subsequently, the publisher of terrestrial maps, Johann-Baptist Homann, published a map of the heavens by Eimmart. Eimmart also produced celestial and terrestrial globes. His scientific archive, which was used by many of his students, was lodged first with his son-in-law Müller in Altdorf; then, after several sojourns, the 56 volumes eventually came to the Imperial Public Library in Saint Petersburg, now the Russian National Library.

A lunar crater is named Eimmart (24°.0 N, 64°.8 E).

A number of Eimmart's manuscripts may be found in the Royal Society of London.

Thomas Klöti
Translated by: *Peter Nockolds*

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Einhard

Born **Maingau, (near Frankfort),** ***circa*** **770**
Died **Seligenstadt, Hessen, (Germany), 14 March 840**

Charlemagne's biographer Einhard recorded the first Western report of a sunspot since (possibly) **Theophrastus**. The event probably occurred between 17 and 24 March 807 and was thought at the time to be a transit of Mercury.

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Einstein, Albert

Born **Ulm, (Baden-Württemberg), Germany, 14 March 1879**
Died **Princeton, New Jersey, USA, 18 April 1955**

Albert Einstein, who transformed and advanced science as only **Isaac Newton** and Charles Darwin had done, was the son of Hermann and Pauline (*née* Koch) Einstein. Einstein's father operated an electrotechnical business but with limited success. During his lifetime, Einstein published, in addition to several books, over 300 scientific articles, many of which are, to this day, the basis of spectacular new advances.

Einstein's contributions spanned a great variety of fields. These include the special relativity theory [SRT] that revised our notions of space and time; brought together under one view electricity, magnetism, and mechanics; dismissed the 19th-century concept of ether; and revealed as a by-product the equivalence of mass and energy ($E = mc^2$). In those first decades of work, Einstein also successfully applied statistical mechanics to explain Brownian motion; proposed a theory that the energy carried by a light wave is quantized ($E = h\nu$), thereby explaining the photoelectric effect (for which he was awarded the Nobel Prize for Physics in 1922); and made contributions to the quantum theory of specific heats, and the concept of stimulated emission, which became a parent of laser physics.

Within months of his birth, Einstein's family had moved from Ulm to Munich. Entering its Luitpold Gymnasium in 1888, he found the school to favor a militaristic style of instruction that he found repugnant. Thus, Einstein resorted to his lifelong passion for self-education. Among those readings that proved influential were, at age 12, a book on Euclidean plane geometry, and popular books on science by Aaron Bernstein and Ludwig Büchner, along with **Alexander von Humboldt**'s *Cosmos*, and (reportedly) Charles Darwin's *Origin of Species*. At age 13 and again at 16, he read **Immanuel Kant**'s *Critique of Pure Reason*. From childhood on, Einstein was exposed to, and became fascinated with, the classics of literature and of music.

In 1894, though 2 years younger than the usual age for entry, Einstein tried to be admitted to the Swiss Polytechnic Institute in Zürich. On failing the entrance examinations (although doing well in physics and mathematics), he entered the Cantonal (Secondary) School in Aarau, Switzerland, where the youngster blossomed in a friendly, supportive atmosphere.

In 1896, Einstein entered the polytechnic to obtain a diploma for high-school teaching, but also took courses on Kant and Goethe. One of his classmates was Mileva Maric′, from southern Hungaria. An early romance and intellectual kinship resulted in their marriage in January 1903. The couple had two sons, Hans Albert and Eduard and a somewhat mysterious daughter, born before they were married, who apparently died quite young. Over time, with Einstein's growing fame pulling him away, and Mileva's earlier moodiness reportedly turning into schizophrenia (which also came to afflict her sister and younger son), the marriage dissolved into unhappiness. Their divorce became final in 1919, whereupon Einstein married his cousin, Elsa Löwenthal.

It took Einstein 4 years (1900–1904) to find a suitable position, that of expert third-class, at the Patent Office in Bern, Switzerland. It has been plausibly argued that his duty of examining applications submitted for electromagnetic engineering devices helped him form critical ideas used in his special relativity, one of his several breakthrough publications in the golden year of 1905.

Over time, Einstein's extraordinary talent became acknowledged, and he accepted a series of academic appointments: at Zürich University (1909), at the German University in Prague (1911), at his old Swiss Polytechnic Institute (1912), and at the Friedrich-Wilhelm University at Berlin (1914). Here, Einstein became well established in the Prussian Academy of Sciences. It was his penultimate move in the long series, the final relocation being to the Institute for Advanced Study in Princeton, New Jersey, in October 1933, where he remained to the end. His first visit to the United States took place in 1921, and he returned there for three working visits at the California Institute of Technology. On returning to Europe from the last of these in early 1933, just when Hitler had been allowed to come to power in Germany, Einstein refused to proceed to his home in Berlin. Indeed, he never set foot in Germany again.

Starting in 1907 and coming to a climax in 1915/1916, Einstein developed, in intense labor, the general relativity theory [GRT], which can be considered a reinterpretation of gravitation as the effect of a curvature of space–time. His long-hoped-for (but never achieved) unified field theory was to embrace the geometrization of electromagnetic fields. Einstein attempted to achieve the stability of a spatially bounded Universe by including a "cosmological constant" (later retracted) and gravitational waves; he also calculated that the gravitational fields of astronomical objects could act as "lenses" to create images of objects located far beyond them. Early successes of the GRT included explaining the degree of deflection of starlight passing close to the Sun (observed in 1919 during a total solar eclipse), the "red shift" of light moving through a gravitational field, and the precession of the perihelion of Mercury. In his years at the Institute in Princeton, he and a few collaborators elaborated the GRT, carrying it forward to the next stage of research. During those years, Einstein also worked (in part with Peter Bergmann and Valentine Bargmann) on a generalization of **Theodore Kaluza**'s higher-dimensional unification of electromagnetism with relativity, which later served as an introduction to contemporary investigations in String Theory.

Einstein responded to these (and later) successes with inner self-confidence and outward expressions of humorous self-derogation.

He once said his greatest gift was his stubbornness, and his ability to remain intrigued by questions that only children might ask. His personal behavior and opinions often alarmed his more conventional colleagues, for he had "Bohemian" tendencies in demeanor and clothing, urged pacifism during World War I, and worked strenuously on behalf of arms control after World War II. Einstein expounded against nationalism and undemocratic, hierarchical rules; he made no secret of his being a Jew and in favor of zionism (if it accommodated the Arabs in Palestine). He opposed religious establishments in favor of a personal "cosmic religion," in the spirit of Baruch Spinoza. In 1952, Einstein felt compelled to decline the offer of the presidency of the State of Israel, feeling that he lacked the quality for leadership needed for the task.

Some of these traits, when added to his exceptional scientific standing, conveyed on him a kind of charisma that still holds sway, although Einstein himself never understood it. It made him the target of attacks by anti-Semites and other enemies from 1920 onward (even threatening his life in 1922), but, on the other hand, flooded him with adoring or opportunistic appeals. A famous example of the latter occurred when three of his colleagues persuaded Einstein to sign the letter of 2 August 1939, warning President Franklin Delano Roosevelt of the danger that the Germans, then about to begin World War II, might construct atomic weapons (as they attempted to do before the Allies).

What might have been the sources of Einstein's extraordinary imaginative powers? A reasonable though all-too-brief answer might begin by noting that each of his three main papers of 1905 – on the quantized notion of light, on explaining Brownian motion, and on what Einstein called modestly a "modification of the teachings of space and time" (*i. e.*, SRT) – seems to be written on completely different topics. Yet, closer study shows that they all stemmed from one preoccupation, namely, with fluctuation phenomena; moreover, they have the same general style and components.

Contrary to one of the popular images of how scientists work, Einstein did not start with some "crisis" brought about by puzzling new experimental facts (nor, contrary to opinions in textbooks, a seminal influence of the failure of the Michelson–Morley experiment). Rather, his dissatisfaction was focused on an asymmetry, or lack of generality in the then-current theory, that others might dismiss as merely aesthetic in nature. He proposed one or two principles, analogous to the axioms of Euclid, and then showed how consequences drawn from them would remove his dissatisfaction. At the end of each early paper, there was a brief and seemingly offhand proposal for experiments that might bear out the predictions of Einstein's theory.

For example, Einstein's paper on the quantum nature of light was motivated by noting an obvious point – that the energy of a palpable body is concentrated and not infinitely divisible. But why should atomicity not apply to both matter and light energy? Here, one glimpses Einstein's fundamental, primary motivation in scientific work, announced in a 1901 letter to Marcel Grossmann: "It is a wonderful feeling to recognize the unity of a complex of appearances which, to direct sense experience, seem to be separate things." All of his 1905 papers endeavor to bring together and unify apparent opposites, removing the illusory barriers between them. Similarly, Einstein's GRT and attempted unified field theory arose from his dissatisfaction with his SRT, because the latter excluded gravitation and therefore seemed to him to require extension. As he once put it, he was driven by the "need to generalize."

These observations intersect, finally, with Einstein's often-expressed interest in a guiding, practical philosophy of science. A key part of this approach was his recognition that a researcher initially cannot work "without any preconceived opinion." He referred to these preconceptions as "'categories' or schemes of thought, the selection of which is, in principle, entirely open to us, and whose qualification can only be judged by the degree to which its use contributes to making the totality of the content of consciousness 'intelligible'." Einstein clearly interpreted such categories in a non-Kantian sense, *i. e.*, as freely chosen. Like other major scientists, his loyalty to and use of presuppositions – to which I refer as themata – were powerful motivations and guides.

Among the themata prominent in Einstein's theory constructions were the following: primacy of formal (rather than materialistic) explanation; unity (or unification, preferably on a cosmological scale); logical parsimony and necessity; symmetry; simplicity; completeness; continuity; constancy and invariance; and causality. In contrast, the quantum mechanics of **Niels Bohr**'s school, with its concepts of fundamental probabilism and indeterminacy, rather than (classical) causality and completeness, was abhorrent to him, and largely explains the unresolved controversy between Einstein and Bohr.

Of Einstein's thematic presuppositions, the one that guided him most to success, but also to his failure to achieve a unified field theory, was the concept of *Einheit* (unity), or, as he once put it, a longing to behold the preestablished harmony that would lift one from the harshness and dreariness of everyday life. Here one glimpses why Einstein and his search, even if uncomprehended in detail by laypersons, continues to be an icon for them.

Gerald Holton

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Elger, Thomas Gwyn Empy

Born **Bedford, England, 27 October 1836**
Died **Bedford, England, 9 January 1897**

Thomas Elger, one of the preeminent amateur lunar observers of the Victorian era, was a leader in British amateur astronomical associations in the late 19th and early 20th centuries. An avid observer and popularizer, he is best known for his lunar map, considered one of the best available until the space age.

Elger lived most of his life in Bedford. His grandfather Isaac, his father Thomas Gwyn Elger (an architect and builder), and he all served as Mayor of Bedford. After graduating from the Bedford Grammar School, he attended the University College in London. Upon completion of his studies, he became a civil engineer and participated in the design of the Metropolitan Railway and the Severn Valley Railway.

When Elger inherited his father's estate in the mid-1860s, he retired from civil engineering to pursue scientific studies, including astronomy and archaeology. Elger moved into his mother's home on Caldwell Street in Bedford and erected his first home observatory. Elger served on numerous Bedford city committees. He was a supporter of the Bedford Library and the Literary Institute, and a founder of the Bedfordshire Natural History Society and Field Club.

Elger was elected a fellow of the Royal Astronomical Society on 10 February 1871. His astronomical observing program was at first a broad one, as evidenced by his early papers, published in *Monthly Notices of the Royal Astronomical Society.* Observations of the colors of the double-star γ Delphini (1872), observations of Venus (1873), observations of Saturn (1887), and important work on Saturn's Crepe ring (1888). However, Elger's major astronomical preoccupation was the Moon, which he observed and wrote about extensively. As he became recognized as an authority on the Moon, Elger wrote the chapters on the Moon for various editions of **Thomas Webb**'s book *Celestial Objects for Common Telescopes* and for *Astronomy for Amateurs, a Practical Manual of Telescopic Research in All Latitudes Adapted to the Powers of Moderate Instruments* (1888), edited by John A. Westwood Oliver.

In 1895, Elger published his classic work *The Moon: A full Description and Map of its Principal Physical Features*. This popular book contained his lunar map, in four sections on a scale of 18 in. to the Moon's diameter, and his descriptions of all of the named features on the nearside. Elger also had the map published as a separate sheet. Elger's map was regarded as one of the better lunar maps until the space age. The map was updated by English selenographer **Hugh Wilkins** and republished in 1959.

From 1887 until near his death, Elger contributed a monthly column "Selenographical Notes" to *The Observatory*. His lunar observations also appeared in a long series of articles in the *English Mechanic*. Elger published the article "Lunar Work for Amateurs" in the *Publications of the Astronomical Society of the Pacific* in June 1891. In that paper he explained how a novice observer could get started observing the Moon.

Elger showed the same zeal for participation in astronomical organizations that was reflected in his civic life. From the founding of the Selenographical Society in 1878 until its folding in 1882, Elger was a member and a regular contributor of lunar observations to the *Selenographical Journal*. Elger was an early and active member of The Liverpool Astronomical Society [LAS], founded in 1881, serving as LAS president for 1 year (1888/1889) and as director of its lunar section for several years. In 1890, after the collapse of the LAS, Elger was a founding member of the British Astronomical Association and served as the first director of the association's Lunar Section. He edited the first three "Reports of the BAA Lunar Section" (1891, 1893, and 1895).

Elger suffered a stroke on 29 December 1896, and died from heart failure as well as the effects of the stroke. He was survived by his widow, Fanny Edith, whom he had married in 1880, and by his two young sons. Shortly after his death, the last of his nearly 200 "Selenographical Notes" in *The Observatory* magazine was published.

A nearside lunar crater at latitude 35° 3′ S, longitude 29° 8′ W was named in Elger's honor in 1912.

Robert A. Garfinkle

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Elkin, William Lewis

Born **New Orleans, Louisiana, USA, 29 April 1855**
Died **New Haven, Connecticut, USA, 29 May 1933**

Using the Yale heliometer, William Elkin measured the parallax of over 200 stars, an unprecedented productivity with that instrument. Working with **David Gill**, Elkin contributed to the accurate measurement of the solar parallax by measuring the parallax of asteroids, and was among the first to apply photography to meteor astronomy.

Elkin was the son of Lewis Elkin, a teacher, private-school owner, and successful carpet manufacturer in New Orleans. His mother Jane (*née* Fitch), a native of Thetford, Vermont, met and married Lewis after moving to New Orleans. William was the only survivor of the five siblings born to their marriage. In 1867, Lewis was appointed commissioner to represent the state of Louisiana at the Paris Exhibition, but within days of the family's planned departure, he died. Friends who were to travel to Paris with the family prevailed on Jane Elkin to make the trip in spite of her tragedy; the family remained in Europe for 17 years. While living in Switzerland in 1870, William Elkin fell ill, probably with a severe case of dysentery, and remained physically frail for the rest of his life. The family lived in a number of countries with the result that Elkin's early education was broad; he acquired excellent skills in French and German and passing ability in Italian and Spanish. He achieved a baccalaureate degree in civil engineering from the Royal Polytechnic School in Stuttgart, Germany, but during that experience came to prefer astronomy as a lifetime occupation.

Elkin studied astronomy with **Friedrich Winnecke**, director of the Strasbourg Observatory, where his fellow graduate students included **Karl Küstner** and **Carl Hartwig**. During his last year in graduate school, Elkin spent 30 minutes in conversation with Gill, who had only recently been appointed Her Majesty's Astronomer at the Cape of Good Hope and was passing through Strasbourg. They agreed on the importance of the heliometer as an instrument of positional astronomy and Gill, taken with his younger colleague's knowledge and personality, invited Elkin to come to the Cape for a visit of several years' duration. Their friendship, formed securely in that brief discussion, lasted until Gill's death some 35 years later. After defending a dissertation on the parallax of α Centauri, Elkin was awarded a Ph.D in 1880. He accepted Gill's invitation and was in residence at the Cape of Good Hope as part of the Gill family from early 1881 until 1884.

At the Cape Observatory, Elkin worked for several years with Gill, doing heliometric parallaxes. Working together on two separate heliometers, they established, with considerable accuracy, the parallax of nine first-magnitude Southern Hemisphere stars. On the basis of the reputation thereby established, Elkin was employed by Yale University in 1884 and moved to New Haven, Connecticut, with his mother. He was the first observer who would make routine measurements with the Yale heliometer. Elkin's first program at Yale University was to reobserve the Pleiades for comparison with **Friedrich Bessel**'s observations (then 50 years old). Of the 69 stars for which Elkin established accurate relative places, he could compare his results with those of Bessel well enough to derive proper motions for 51 of the stars, and to confirm with certainty that they moved in a common direction as members of the cluster.

Elkin also measured all of the stars he could see within 100′ of the North Celestial Pole, Harvard's North Polar Sequence, at the request of **Edward Pickering**. He next undertook to determine the parallax of the ten northern first-magnitude stars and tied those into the results that he and Gill had first reported. While his accurate parallax determinations are important individually, a more important conclusion that Elkin drew from the work that he and Gill had completed was that for the most part, the brightest stars are not necessarily close to the Earth, but instead are intrinsically very bright. On the other hand, stars with large proper motions were clearly much closer to the Earth and therefore better candidates for accurate heliometric measurements.

Elkin, with two assistants, Frederick L. Chase and Mason Smith, undertook a program to measure the parallax of all stars with large proper motions. The result of this program was the addition of another 238 parallaxes to the catalog, an accomplishment that **Frank Schlesinger** rated as the most important contribution to the knowledge of stellar distances up to that time. It was for this work that the French Academy of Sciences awarded Elkin the Lalande Prize in 1908.

Elkin next took on a cooperative program with Gill to determine the solar parallax using asteroids. Between 1888 and 1894 he observed minor planets (7) Iris, (12) Victoria, and (80) Sappho in this program, but was unable to participate in the Eros campaign because of the faintness of the asteroid and its unfavorable location for heliometer measurements from New Haven. Observatories at Oxford, England, and Leipzig, Germany, participated, along with Yale Observatory and the Cape Observatory. The solar parallax derived from these measures, 8.802″ with a probable error of only 0.005″, was more confidently accepted than measures derived from the transits of Venus. Equally important consequences of this work were the subsidiary determinations of the mass of the Moon, constants of nutation and aberration, the dynamic flattening of the Earth, and refinement of the lunar equation. From 1891 to 1892 Elkin was also involved in a program to determine the orbits of Jupiter's satellites and, from those data, he recomputed the mass of Jupiter.

Elkin was the first astronomer in America to use photography for meteor observation. His Geminid radiant in 1893 was based on only three meteors, but they intersected in an incredibly small area that left little doubt. Elkin further attempted to determine meteor velocities using a rotating sector disk to mark the photographic tracks into precise segments. While many altitudes were determined with simultaneous photographs taken from two stations in this program, Elkin was never satisfied with the probable errors and problems associated with his observations.

In addition to the Lalande Prize mentioned above, Elkin was honored by election as a Foreign Associate of the Royal Astronomical Society, and by election to the National Academy of Sciences.

In June 1896, Elkin replaced **Hubert Newton** as the director of the Yale Observatory, a position he held until his retirement in 1910. Elkin had married Catherine Adams of New Haven in 1896; their marriage remained childless, but they enjoyed common interests in music and photography during his lengthy retirement.

Thomas R. Williams

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Ellerman, Ferdinand

Born **Centralia, Illinois, USA, 13 May 1869**
Died **Pasadena, California, USA, 20 March 1940**

A skilled and dedicated solar and stellar spectroscopist and photographer, Ferdinand Ellerman's professional relationship with **George Hale** lasted 46 years, and involved him in the design and construction as well as the operation of two major observatories. Ellerman can rightly be credited with conducting the majority of the observational projects through which Hale's early discoveries were achieved.

Ellerman was educated in local Illinois schools and moved to Chicago in 1886, where he worked in several commercial organizations, developing exceptional abilities in photography and in the use of machine tools. This unusual combination of skills attracted the attention of young Hale, who in 1892 hired Ellerman as an assistant

at his private observatory, in Kenwood, Illinois. Ellerman followed Hale to Yerkes Observatory in 1895, and to Mount Wilson Solar Observatory in 1905. He was a member of the Astronomical Society of the Pacific and of the American Astronomical Society, and in 1912 received an honorary Masters degree from Occidental College. Ellerman retired from Mount Wilson Solar Observatory in 1938.

Ellerman's work was carried out in close collaboration with Hale, who always duly acknowledged the importance of Ellerman's contributions. Ellerman was heavily involved in the development and use of the spectroheliograph. He carried out a good share of the solar observational work at Yerkes Observatory and Mount Wilson Solar Observatory, leading to the discovery of new solar phenomena, such as solar vortices and various properties of the magnetic fields of the Sun and of sunspots. He also obtained most of the nighttime observations for Hale's research program on carbon stars. Ellerman's instrumental skills played an important role in the development of Mount Wilson Solar Observatory, which he had already visited in 1904 with Hale. Ellerman took on the responsibility for the solar photographic program at Mount Wilson Solar Observatory, and the "temporary" focal-plane solar camera he constructed in 1905 for the Snow telescope proved so superior to its attempted successor that it was never replaced, and remains in use to this day.

Throughout his life, Ellerman remained involved in civic affairs, serving on school boards in Williams Bay, Wisconsin (home community to Yerkes Observatory) and Pasadena, California. A lover of the outdoors, Ellerman was fondly remembered by many visitors to Mount Wilson Solar Observatory for his guided hiking, climbing, and fishing excursions in the neighboring hills.

Peter Riley

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Ellery, Robert Lewis John

Born **Cranleigh, Surrey, England, 14 July 1827**
Died **Melbourne, Victoria, Australia, 14 January 1908**

Robert Ellery was director of the earliest permanent observatory in Australia and directed the installation and initial operation of the Great Melbourne Telescope, the first large reflecting telescope in the Southern Hemisphere. The son of John Ellery, a surgeon, and his wife Caroline (*née* Potter), Robert Ellery attended the local grammar school and was trained for a medical career. However, his growing interest in astronomy led to contact with Greenwich Observatory where he developed friendships with the staff and became acquainted with the use of instruments, eventually becoming a professional astronomer.

In 1851 Ellery immigrated to the Australian colony of Victoria. The increase in shipping associated with the gold rush created the need for accurate time for rating chronometers. Ellery proposed to the Melbourne press that a nautical observatory be established at nearby Williamstown. The government responded by appointing Ellery to run the modest establishment in 1853.

Almost single-handedly Ellery built up a functioning observatory. The first telegraph line in the colony connected Williamstown to Melbourne to coordinate the simultaneous dropping of time balls. By then, Ellery's standing was such that, in addition to his astronomical duties, he was appointed director of the geodetic survey begun in 1856.

A new observatory, superseding both the Williamstown operation and Dr. Georg Neumeyer's Meteorological and Magnetic Observatory, was established in Melbourne in 1863 with Ellery as director. This new observatory provided the focus for reviving a plan for a large reflecting telescope in the Southern Hemisphere. Sir **Edward Sabine**, and later, in 1849, **Thomas Robinson** of Armagh Observatory, proposed such a telescope to continue **John Herschel**'s observations of nebulae at the Cape of Good Hope, but the idea was abandoned when **George Airy** failed to support it.

With interest expressed from Melbourne in 1862, the scheme was revived and a giant reflector ordered from **Thomas Grubb** of Dublin in 1866. This Cassegrain telescope with equatorial mounting and a 48-in. speculum metal primary mirror was installed in 1869.

The intended use of the telescope was primarily to document southern nebulae by hand drawing. Excessive vibration of the telescope tube under the influence of local winds and other factors combined to make visual observation with the telescope difficult. Despite difficulties with the new telescope, Ellery's assistants made some fine drawings of nebulae. Unfortunately, although the hand-drawn representations of nebulae were well done, they could not reasonably be compared with earlier observations made with smaller telescopes and under different conditions. Excellent photographs of the Moon were taken in the 1870s and for a period were considered the best available.

The Great Melbourne Telescope was among the last in the tradition of large reflectors constructed in Ireland in the 19th century, and in some respects perhaps the finest. Nevertheless, it was at best a mixed blessing. It was not possible to publish the delicate nebula drawings. The telescope was not sufficiently stable to allow for the long exposures necessary for either nebular or stellar photography, nor was it suited for spectroscopy. Ellery's skill in refiguring and polishing one of the 48-in. mirrors of the Great Melbourne Telescope made it "undoubtedly more perfect in figure than it ever has been" (*Annual Report for 1890*, p. 6). Despite this, the achievements of the observatory largely depended on other instruments.

A 5-in. transit circle delivered by Troughton & Simms in 1861 was used for meridian observations until 1884 when the same firm delivered an 8-in. instrument modelled on the transit circle at Cambridge Observatory. Ellery's mastery of meridian astronomy is reflected in the series of general catalogs of meridian observations of stars published in 1869, 1874, and 1889. Airy commented, in the mid 1870s, that the Melbourne catalogs of Southern Hemispheric stellar positions were the best that had been published.

The last major undertaking during Ellery's directorship was Melbourne Observatory's share in the *Carte du Ciel*, the international astrographic mapping project initiated in Paris in 1887. Australian participation in the project was agreed to by **Henry C. Russell**, director of Sydney Observatory, with the declination zone −65° to the South Celestial Pole assigned to Melbourne Observatory. The venture began with great enthusiasm, and exposures of the plates at both observatories were completed in a timely manner. Measurement of the plates for both Sydney Observatory and Melbourne Observatory was carried out at the latter observatory until 1915. The plates were eventually transferred to Sydney where the measurements were finally completed.

Victoria suffered severely in the financial depression of the early 1890s, leading to cutbacks of staff at the observatory. Ellery retired in 1895 but continued to live at Observatory House and was appointed to the observatory board of visitors.

Ellery was associated with many official and public bodies in Victoria in addition to his work at the observatory. He headed the Geodetic Survey until 1874, served with the Torpedo Corps of the local Volunteer Force, and presided at the Intercolonial Meteorological Conferences held in Melbourne in 1881 and 1888 and at the meeting of the Australasian Association for the Advancement of Science there in 1900. Ellery joined the Royal Society of Victoria in 1856, serving as its president from 1866 until 1885, and published numerous papers in its journal. He was also a keen apiarist. His achievements and services were recognized by his election as a fellow of the Royal Astronomical Society (1859) and fellow of the Royal Society (1863). In 1889, he was awarded the Companion of Saint Michael and Saint George [CMG].

In 1854 Ellery married Jane Shields, but she died 4 years later. He married Jane's younger sister, Margaret, in 1859. Enfeebled by an attack of paralysis, Ellery died at Observatory House, survived by his second wife and a daughter from his first marriage.

Julian Holland

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Ellicott, Andrew

Born **Buckingham, Pennsylvania, (USA), 24 January 1754**
Died **West Point, New York, USA, 20 August 1820**

American mathematician, surveyor, and astronomer, Andrew Ellicott laid out the nation's capital, trained Meriwether Lewis to conduct astronomical observations on the Corps of Discovery's expedition with William Clark, and became a professor of mathematics in the United States Military Academy at West Point, New York.

Ellicott was the son of clockmaker Joseph Ellicott and his wife Judith Bleaker. His early education was completed at a Quaker school in Solesbury, Pennsylvania. At the age of 15, he began to study physics, mathematics, and astronomy under Robert Patterson (who later taught those subjects at the University of Pennsylvania). Ellicott's family moved to Baltimore County, Maryland, in 1772 and likewise operated a milling business. In 1775, he married Sarah Brown; the couple had ten children. During the Revolutionary War, Ellicott served with the Maryland militia and rose to the rank of captain (later major). After his father's unexpected death in 1780, he managed both the mills and the family's clockmaking enterprise.

Ellicott's skills as a surveyor were called upon when he was appointed to a commission (1784) that surveyed the boundary between Pennsylvania and Virginia (now West Virginia), a process requiring 6 months of hard labor. He also participated (with Philadelphia astronomer **David Rittenhouse**) in the survey that established the western boundary of Pennsylvania (1786), and in 1787 he surveyed the state's northern boundary (on the 42nd parallel of latitude), which later included the Presque Isle triangle (now Erie, Pennsylvania). For making latitude observations, Ellicott preferred to use a zenith sector, while many of his longitude measurements were derived from observations of the eclipses of Jupiter's Galilean satellites, especially Io. During a visit to Philadelphia, Ellicott was elected to the American Philosophical Society; in 1789, he relocated his family to that city.

In 1791, Ellicott was appointed by President George Washington to survey the 10-mile-square tract of land ceded from Maryland and Virginia that became the District of Columbia, future site of the nation's capital. At first working under difficult wintertime conditions, he was assisted for several months by the African American almanac-maker **Benjamin Banneker**. Ellicott's survey was not completed until 1793; his account of the astronomical observations was later published in the *Transactions of the American Philosophical Society* (1799).

With his reputation established, Ellicott was again appointed by Washington in 1796 to work with Spanish commissioners to establish the boundary between the United States and the Spanish territory of Florida, along the 31st parallel of latitude. This enormous undertaking stretched from the Atlantic Ocean to the Mississippi River and occupied Ellicott and his assistants from 1798 to 1800. While off the territory's coast in November 1799, Ellicott observed the great Leonid meteor storm and reported:

> About two o'clock in the morning I was called up to see the shooting of the stars (as it is vulgarly termed), the phenomenon was grand and awful, the whole heavens appearing as if illuminated with sky rockets, flying in an infinity of directions, and I was in constant expectation of some of them falling on the vessel. They continued until put out by light of the sun after daybreak.

In the conduct of his survey, Ellicott also made numerous observations on the region's flora and fauna, which in turn were described in his publication of the results (*The Journal of Andrew Ellicott*… (1803)). As a reward for these labors, he was offered (but declined to accept) the post of surveyor-general of the United States, extended by President Thomas Jefferson. Ellicott urged Jefferson to support the establishment of a national observatory.

In 1801, Ellicott was appointed by the governor of Pennsylvania as secretary of the State's Land Office and thus relocated to Lancaster, Pennsylvania, whose latitude and longitude he promptly determined. He maintained a correspondence with Jefferson and French astronomer **Jean Delambre**. At Jefferson's request, Ellicott trained Meriwether Lewis (between April and May 1803) in the use of a sextant, chronometer, and other astronomical instruments to be used on Lewis and Clark's exploration and mapping of the Louisiana territory.

Following a political turnover in 1808, Ellicott was dismissed from the Land Office but was chosen in 1811 to survey the northern boundary between Georgia and North Carolina. In 1813, he was appointed professor of mathematics at West Point by President James Madison and retained this position until his death.

The Georgian-style building from which Ellicott operated the Pennsylvania Land Office, at 123 North Prince Street, Lancaster, was completely restored in 1981 (as the Sehner–Ellicott–von Hess House). It is listed on the National Register of Historic Places and is now occupied by the Historic Preservation Trust of Lancaster County. Three of Ellicott's telescopes are preserved at the National Museum of American History, Smithsonian Institution, while his papers can be found in the Library of Congress and the United States National Archives.

Jordan D. Marché,II

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Ellison, Mervyn Archdall

Born **Fethard-on-Sea, Co. Wexford, Ireland, 5 May 1909**
Died **Dublin, Ireland, 12 September 1963**

Mervyn Ellison was a solar astronomer of international repute. As an amateur and later as a professional, Ellison studied solar flares and their terrestrial effects.

Ellison was the third son of the distinguished amateur astronomer and telescope maker, Reverend William Frederick Archdall Ellison (1864–1936), rector of Fethard-on-Sea with Tintern in County Wexford from 1908 until 1918 when he was appointed director of Armagh Observatory. In 1920 the elder Ellison published *The Amateur's Telescope*, which was the forerunner of the famous three-volume set on amateur telescope making edited by **Albert Ingalls**.

Mervyn Ellison was educated at home and later at Armagh Royal School. He acquired his practical skills in astronomy from his father and had full access to the telescopes of Armagh Observatory. At the age of 13 he was making detailed drawings of sunspots and features on Mars and Jupiter. Ellison's micrometric observations of double stars with the 10-in. Grubb refractor resulted in his first paper being accepted for publication by the Royal Astronomical Society.

Ellison entered Trinity College, Dublin, in 1927 to read physics under professor R. W. Ditchburn. He had a brilliant academic career, graduating with a first class honors degree in experimental physics and gaining an M.Sc. degree in 1932. Before his mother's death in 1933, Ellison spent a year teaching at Armagh Royal School before his appointment as senior science master at Sherbourne School, Dorset. In 1934 he married Patricia, only daughter of Crosthwaite Herron, MD of Armagh. They had one son and two daughters.

At Sherbourne, Ellison constructed his own spectrohelioscope after the design of **George Hale**, grinding and polishing his own mirrors and lenses. He used this instrument to observe solar flares in hydrogen alpha (Hα) light; the results were published in the *Monthly Notices of the Royal Astronomical Society*. During World War II Ellison served in the Operational Research Group of the Admiralty under professor **Patrick Blackett**. When Ellison returned to Sherbourne, a very high sunspot maximum was in progress. He fitted a spectrograph to his spectroheliograph so that after locating an interesting chromospheric feature, he could take its spectrum. On 25 July 1946 Ellison obtained a superb spectrum of a great flare over a giant sunspot that showed the Hα line in emission extending for 20 Å. He continued visual monitoring of flares and showed that for intense flares the peak intensity had a short duration, which he termed the "flash phase."

Ellison began his professional career in 1947 with his appointment as principal scientific officer and deputy director at the Royal Observatory, Edinburgh. The Sherbourne instrument was remounted at Edinburgh so Ellison could continue his studies of flares and prominences. He adopted photometric methods for measurement of flare brightness in order to follow the change of flare intensity with time. Ellison used long-wave radio receivers to record disturbances of the ionosphere and to correlate these with solar activity. The results of his work over 11 years in Edinburgh were published in the *Publications of the Royal Observatory, Edinburgh* and in the *Monthly Notices of the Royal Astronomical Society*. During this time Ellison was a joint editor for *The Observatory* for 5 years. His popular book *The Sun and Its Influence* was published in 1955 and later translated into Russian and Spanish.

In 1952 the United Kingdom National Committee for the International Geophysical Year [IGY] invited Ellison to be its representative for solar activity. From 1955 he became a member of the committee for the study of solar–terrestrial relationships under the International Council of Scientific Unions. Later he was appointed world reporter for solar activity of the IGY, which began in July 1958. Early in 1958 Ellison went to South Africa to install an automatic Lyot heliograph at the Royal Observatory, Cape of Good Hope, as part of Britain's contribution to the IGY. The heliograph took 35-mm photographs of the full disk of the Sun in Hα light at 1-min intervals.

In November 1958 Ellison was appointed senior professor in the School of Cosmic Physics of the Dublin Institute for Advanced Studies; he took up residence at Dunsink Observatory. The Cape and Dunsink observatories operated the heliograph jointly for the next 5 years. The results were published in *Dunsink Observatory Publications*, Vol. 1, nos. 1–4 under the joint authorship of Ellison, Susan M.P. McKenna, and John H. Reid.

With the conclusion of the IGY, as general editor Ellison had the onerous task of organizing the publication of daily charts showing every solar feature. This great work appeared as Vols. 21 and 22 of the *Annals of the International Geophysical Year*.

In 1963 Ellison was making plans for the International Quiet Sun Year. He was to have chaired a committee meeting at Berkeley, California, USA, in June. However, he had to cancel his attendance on account of an illness that soon proved fatal. In a tribute, Ellison's lifelong friend, **Eric Lindsay** of Armagh Observatory, praised "his characteristic simplicity, unbiased judgment, wise administration and loyal friendship."

Ellison was elected a fellow of the Royal Astronomical Society in 1938 and served on its council from 1940 to 1950. He was elected a fellow of the Royal Society of Edinburgh in 1944 and was awarded the D.Sc. of the University of Dublin in 1944. Ellison was Vice-President of Commission 10 of the International Astronomical Union, a member of the Royal Irish Academy, and a member of the British Astronomical Association. The International Astronomical Union named the lunar crater at 55° 1′ N and 107° 5′ W in his honor.

Ian Elliott

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Elvey, Christian Thomas

Born **Phoenix, Arizona, USA, 1 April 1899**
Died **Tucson, Arizona, USA, 25 March 1970**

American stellar astronomer and geophysicist Christian Elvey contributed to the discovery of stellar rotation and the mapping of the interstellar medium. He was the son of John A. and Lizzie Christina (*Née* Miller) Elvey and married Marjorie Purdy in 1934. They had two children, Thomas Christian and Christena Vivian. Elvey earned an AB (1921) and AM (1923) at the University of Kansas and was instructor in astronomy there (1921–1925). Following fellowships in astronomy at the University of Chicago (1925–1926), he did research at the Dearborn Observatory and was instructor in astrophysics at Northwestern University (1926–1928). From 1928 Elvey worked at the Yerkes Observatory, notably with **Otto Struve**, earning a Ph.D. from the University of Chicago (1930) with a thesis on the contours of spectral lines in the spectra of stars. His thesis demonstrated that many stars have detectable rotation and that the rotation periods for close binary systems are often synchronized with their orbital periods. Elvey remained as assistant professor at the University of Chicago until 1935, when he became astronomer and assistant to the director of McDonald Observatory. In Texas, he developed an interest in the diffuse light of the night sky. From 1942 to 1951 he studied the sky and the aurorae from the Naval Ordnance Test Station at Inyokern, California, progressing to head of staff. In 1952, Elvey moved to the University of Alaska in Fairbanks where he was head of the department of geophysics and director of the Geophysical Institute (1952–1963), vice president for Research and Advanced Science (1961–1963), and University Research Professor (1963–1967). He was president of the Geomagnetism and Astronomy Section of the American Geophysical Union [AGU] (1961–1964) and member of several other scientific societies.

Elvey was interested in stellar spectra and studied a wide range of subjects from the 1920s to the 1940s. With Struve and others at Yerkes and McDonald observatories, he determined spectroscopic binary orbits and made studies of line strengths and the profiles of hydrogen and helium lines in stellar spectra. His work in spectroscopy strongly contributed to understanding stellar atmospheres and stellar rotation. Elvey was also interested in galactic nebulae, and while at McDonald Observatory, conducted studies of nebular spectra with a special 150-ft. nebular spectrograph. A 1930 paper with **Albrecht Unsöld** and O. Struve determined the density and distribution of the interstellar medium using the strengths of the interstellar Ca II lines for the first time. In 1932 Elvey began to publish papers on light from the gegenschein and the day and the night sky. From about 1948 Elvey published papers on the night sky and aurorae and pioneered in making observations from aircraft.

The University of Alaska awarded Elvey an honorary doctorate in 1969 at the opening of the C. T. Elvey building named in his honor. A 74-km-diameter lunar crater is named for him.

Gary A. Wegner

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Emden, Robert

Born **Saint Gallen, Switzerland, 4 March 1862**
Died **Zürich, Switzerland, 8 October 1940**

Swiss–German theoretical physicist Robert Emden is best known for the Lane–Emden equation, which can be used to describe the internal structure of gaseous spheres (stars) under certain simplifying assumptions.

Emden was educated in Switzerland and Germany and married the sister of **Karl Schwarzschild**. He was appointed professor of physics at the Technische Hochschule in Munich in 1889 and as professor of meteorology there in 1907. He was named honorary professor of astrophysics at the University of Munich in 1924, retiring in 1934 and returning to Switzerland.

A primary goal of studies of stellar structure in that period was to be able to describe the internal distribution of temperature, pressure, and density in terms of physics known from terrestrial laboratories and use this description to try to understand the observed relationships among stellar masses, sizes, brightnesses, and surface temperatures. The pioneering investigation was that of **Jonathan Lane** who, in 1870, wrote "On the theoretical temperature of the sun, under the hypothesis of a gaseous mass maintaining its volume by internal heat and depending on the laws of gases as known to terrestrial experiments." This was followed and amplified by the investigations by **August Ritter** and **William Thomson** (Lord Kelvin). The latter was particularly certain that the source of solar and stellar energy was gravitational contraction, and the energy release therefore distributed throughout the volume.

These investigations culminated in the work of Emden in the early 20th century. His equations described stars as polytropes, *i. e.*, gases with particularly simple relationships between pressure and density, measured by a single index, *n*, whose numerical value could be anything between 0 and 5. The key feature of these solutions, called polytropes, is that they do not require you to know what the energy source is, but only to know that pressure must balance gravity for stars to be stable and that energy must be transported outward fast enough to maintain observed luminosities. (Emden's work on the structure of the Sun and stars occurred during the period when the only known energy source *was* gravitational contraction, so his 1907 estimate of the age of the Sun was 22 million years.) Emden himself calculated tables of numerical solutions to the equations for a number of values of n, which continued to be used well down into the era of early digital computers. Somewhat later, **Arthur Eddington** showed that $n = 3$ corresponds to a star made of an ideal gas. Then **Ralph Fowler** found that $n = 3/2$ describes a completely degenerate star or white dwarf. William B. Bonnor in 1956 applied these ideas to homogeneous, isotropic models of the Universe. The solutions are called Bonner–Ebert spheres, and it can be shown that they are unstable for certain values of n. Polytropic models, and thus the Lane–Emden equation, continue to be used down to the present when it is desired to incorporate a great deal of additional complex physics (for instance general relativity, dynamically important magnetic fields, or highly distorted shapes) into a stellar model.

Ian T. Durham

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Empedocles of Acragas

Born **perhaps Acragas (Agrigento, Sicily, Italy), *circa* 493 BCE**
Died **433 BCE**

Empedocles, one of the followers of **Parmenides** in the Eleatic school of philosophers, is best known for his theory (later adopted by **Aristotle**) that everything in nature was composed of four elements, in varying amounts: earth, air, fire, and water. Empedocles also hypothesized two opposing forces, love and strife; the tension between these two produced cycles of change in the Universe. He may have realized that the Moon reflects sunlight and travels around the Earth; he may also have believed that the Moon caused eclipses of the Sun. In his cosmology the sky was an egg-shaped crystal surface with the stars attached; the planets moved freely. Empedocles was also a physician and generated some theories in medicine.

Katherine Bracher

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Encke, Johann Franz

Born **Hamburg, (Germany), 23 September 1791**
Died **Spandau, (Berlin, Germany), 26 August 1865**

Johann Encke was the leading German astronomer of his generation, contributing substantially to celestial mechanics, observation of the Solar System, and the professional development of the German-speaking astronomical community. He was the son of Johann Michael Encke and Marie Misler.

Educated at Göttingen University as a student of **Carl Gauss**, Encke, the eighth child of a Lutheran Pastor of Hamburg, began his career as a professional astronomer thanks to Gauss' recommendation for a position as assistant at the Seeberg Observatory near Gotha. Having already published calculations of orbital elements of several of the newly discovered minor planets as a student, Encke distinguished himself in his examination of the orbit of the third known short-period comet (2P/Encke), discovered in November 1818 by **Jean Pons** and now called Encke's comet (but not by Encke himself in his many publications). Restricted to the inner Solar System, with a period of only 3 years, the orbit of Encke's comet changes constantly due to the relatively large gravitational attraction of the nearby planets, particularly Jupiter. To solve this problem Encke devised a convenient mathematical reduction of the series of differential equations representing its perturbed orbital elements.

Applied to a wide variety of objects with relatively perturbed orbits, Encke's method failed completely, even when applied by a variety of investigators in ever more sophisticated ways to explain the complexities of motion of the comet. In the 20th century it was shown that the orbit of this much-studied comet cannot be explained by Newtonian laws alone, even assuming (as Encke and others did) motion in a resistive medium; the loss of mass due to outgassing has to be taken into consideration.

Having made significant improvements in the instrumentation of the Seeberg Observatory, Encke was offered a membership in 1825 in the Berlin Academy of Sciences and the directorship of its observatory. Here he not only expanded the publication of its *Berliner Astronomisches Jahrbuch* and delivered well-attended lectures on astronomy at the request of the Ministry of Education, but also oversaw a substantial renovation of the observatory itself, including a new structure at a more appropriate suburban site and new, research-grade instruments, including a large Fraunhofer refractor. An ongoing project of the academy, now put under Encke's direction, was the preparation of accurate star charts. The new instruments and the new charts were both crucial in the short successful hunt for Neptune. In 1838, he discovered a gap in Saturn's rings (between the A and F rings), later known as Encke's gap.

Perhaps Encke's greatest triumph was the observation at the Berlin Observatory of the planet Neptune by his assistant **Johann Galle** the day after receipt of its predicted position calculated by **Urbain Le Verrier**, in contrast to more than 6 months of unsuccessful search at the Cambridge University Observatory and months of bureaucratic delay at the Paris Observatory. Instrumentation ordered and installed by Encke, accurate charts compiled under his direction, and observers he had trained all contributed to this signal accomplishment.

In 1844 Encke received the recognition of appointment as professor of astronomy at the University of Berlin, the leading university in Prussia. Among his many influential students may be mentioned **Benjamin Gould**, **Franz Brünnow**, author of a leading astronomical textbook, Galle, and **Giovanni Schiaparelli**. A congenial man, Encke advised **Friedrich Struve** on how to equip a new observatory in Russia as early as 1820 and acknowledged in 1852 that **George Bond**, of Harvard College Observatory, had preceded him, in an application of perturbation theory. Encke retired as professor in 1863 but continued as director of the observatory until his death.

Michael Meo

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Engel, Johannes

Born **Aichach, (Bavaria, Germany), probably 2 March 1453**
Died **Vienna, (Austria), 29 September 1512**

As **Georg Peurbach**'s successor, Johannes Engel strove to calculate new planetary tables.

Engel began his studies in Vienna in 1468 as a pupil of **Johann Müller** (Regiomontanus). In August 1472, he registered at Ingolstadt, and became a master of arts in 1474. In 1489–1491, Engel worked in Augsburg as a proofreader for the printer Erhard Ratdolt, well known for the publication of numerous astronomical works (and previously active in Venice). In 1492, he returned to Ingolstadt and studied medicine. Until his death he earned his living as a doctor in Vienna, and was thus able to pursue his interests in astronomy and astrology.

In his *Almanach novum*, Engel stated that in the Dominican monastery in Vienna there was a manuscript of Peurba, in which he noted that the traditional planetary theory, and both the Alphonsine and Bianchini's Tables, did not represent the motion of the planets with sufficient accuracy, but that this was common knowledge. When in Vienna, Engel established from his own observations that these differences, as well as those between his data and those given in **Johannes Stöffler**'s yearbook, amounted to about 1–3°. This reveals Engels as a serious working astronomer who was aware of the deficiencies of contemporary astronomy. He also had at his disposal contemporary information regarding the works and projects of Müller, which are extremely valuable to us, because of the lack of reliable sources.

Engels compiled numerous astrological calendars and yearly prognostications, the oldest of which is for 1484, and which appeared (partly) both in German and in Latin. His *Opus Astrolabii plani in tabulis: a Johanne angeli liberalium magistro* (1488) was a fundamental work for astrology. It contains numerous tables for astrological calculations (places of the Sun, the houses, temporal hours, and their astrological characteristics, as well as 360 sample horoscopes, decorated with little images for locating the ascendant for each degree of any zodiacal sign). An edition of a number of works by the Islamic scholar **Abū Maˤshar**, *De magnis conjunctionibus*, that he had edited appeared in 1489, and was of great significance in the introduction of the astrological theory of conjunctions to later astrology.

Jürgen Hamel
Translated by: *Storm Dunlop*

Alternate name

Angelus

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Engelhard, Nicolaus

Flourished **The Netherlands, 1738**

Groningen professor Nicolaus Engelhard was a Copernican proponent in the Netherlands.

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Ensor, George Edmund

Born **New Zealand, 1873**
Died **Pretoria, South Africa, 8 June 1943**

A radiographer by profession, George Ensor's main avocational interest was in variable star astronomy. Ensor arrived in South Africa as part of a contingent from New Zealand in connection with the South African War and remained there after the war was over. He served as the director of the Astronomical Society of South Africa's [ASSA] variable star section and submitted nearly 15,000 observations to the American Association of Variable Star Observers during the period 1926–1940. Ensor was also an active lunar occultation observer for the Greenwich Observatory. He discovered comet C/1925 X1 and shared the discovery of comet C/1932 G1 with another South African amateur, Hendon Edgerton Houghton. His reputation in astronomy was such that Astronomer Royal **Frank Dyson** consulted him on possible sites for the Radcliffe Observatory, which was ultimately located within a few meters of the site recommended by Ensor.

Thomas R. Williams

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Ephorus

Flourished **Cyme (near Izmir, Turkey), 4th century BCE**

In 372 BCE, Greek historian Ephorus reported seeing a comet break into two. It has been speculated that this comet is the ancestor of **Carl Kreutz**'s sun-grazing comets.

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Epicurus of Samos

Born **Samos, (Greece), *circa* 341 BCE**
Died **Athens, (Greece), *circa* 271 BCE**

Epicurus based his astronomy on his general metaphysical views, and put it in the service of his ethics.

Epicurus was born in the Athenian colony of Samos, an island in the Mediterranean Sea. He founded the Garden, which was a combination of philosophical school and community, around 306 BCE in Athens. Epicurus died from kidney stones. He had no descendants, but the Garden continued as a thriving philosophical community for centuries after Epicurus' death, and Epicureanism became one of the major philosophical systems in the Greco–Roman world, competing with Stoicism for people's allegiances.

Epicurus was an atomist. According to atomism, which was first proposed by Leucippus and Democritus, everything in the world is made up of atoms, uncuttable bits of matter, moving through empty space, and everything in the Universe can be explained in terms of the mechanical interaction of these atoms. In his ethics, Epicurus preached that the point of life is to gain tranquility for oneself, and that the fear of the gods and of an unpleasant afterlife destroys one's tranquility.

Epicurus insisted that all terrestrial and celestial phenomena are nothing more than the result of the motions, reboundings, and entanglements of various types of atoms. Explanations of these phenomena in such mechanistic terms, Epicurus thought, should *displace* explanations that appeal to the will of the gods. Epicureans opposed divination and astrology, since the movements of the heavens do not reveal any sort of divine plan and belief in divine providence and divine interference breeds anxiety. Epicurus was directing his attack both against the popular Olympian religion and against the cosmologies of philosophers like **Plato**, who said that the gods are responsible for the orderly motions of the heavenly bodies.

Epicurus believed that there are an infinite number of atoms, which have existed for an eternity of time, moving through an infinite expanse of space. Because of this, ours is only one out of an infinite number of worlds, and our world is not at the center of the cosmos, since there is no center. Since an infinite number of worlds exist, there must be life on other planets, including intelligent life. Although the Universe as a whole is eternal, our particular cosmos, which is a chance conglomeration of atoms, has a beginning in time and will eventually fall apart.

In all of these doctrines, except concerning the eternity of the Universe, Epicurus opposed the views of **Aristotle**. Aristotle promulgated a geocentric view of the Universe and believed that this cosmos (the Earth, Sun, planets, and stars) is eternal and spatially limited. Aristotle's cosmology became the Church's official cosmology in the Middle Ages, but during the Renaissance and because of early modern reaction against scholastic neo-Aristotelianism, interest in Epicurus' astronomy was revived, particularly by the French philosopher **Pierre Gassendi**.

Even though he thought that mechanistic explanations of astronomical phenomena are necessary in order to dispel our fear of godly meddling, Epicurus believed that natural science has no value in itself. Epicurus offered atomistic and naturalistic explanations for a wide range of celestial and meteorological phenomena, but his particular explanations are largely *ad hoc* speculations and did little to advance astronomy.

Epicurus said that in many cases a phenomenon may permit multiple explanations, and that we must take care not to rule out any possible explanation too hastily. Epicurus followed his own method, enumerating many possible explanations for various phenomena. For instance, Epicurus said that solar and lunar eclipses could be caused either by the extinguishing of their light, or because their light is blocked by another body, and he listed four different explanations of thunder in terms of atomic motions.

Most of Epicurus' own writings are lost, but the main outlines of his philosophy are contained in three of his letters: the *Letter* *to Pythocles*, which summarizes his explanations for celestial and meteorological phenomena, the *Letter to Menoeceus*, which summarizes his ethics, and the *Letter to Herodotus*, which summarizes his metaphysics. Epicurus' arguments for an infinite number of worlds, the absence of divine intervention in the world, and the doctrine of multiple explanations can be found in the *Letter to Herodotus* sections 45 and 73–80. All three letters are preserved by the ancient biographer and gossip, Diogenes Laertius, in Book ten of his *Lives of the Philosophers*.

Epicurus' own writing is often compressed and unclear. The Latin poet **Lucretius**, however, penned *De Rerum Natura*, a masterful exposition in hexameter of Epicurus' metaphysics, philosophy of mind, and natural science. The end of Book II gives the Epicurean argument for an infinite number of worlds and explicitly states that there are many worlds in which people and nonhuman animals exist. The first half of Book V contains the Epicurean arguments that the processes of the Universe occur for no divine purpose, and that the world is not eternal. Books V and VI contain Epicurean explanations for various astronomical and meteorological phenomena.

Timothy O'Keefe

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Eratosthenes of Cyrene

Born **Cyrene (near Darnah, Libya), *circa* 274 BCE**
Died **Alexandria, (Egypt), *circa* 194 BCE**

Eratosthenes, Greek scholar, scientist, and mathematician, is chiefly remembered for devising and performing the first measurement of the circumference of the Earth, and for inventing the algorithm known as the sieve of Eratosthenes.

According to the *Suda* Eratosthenes was born in the 126th Olympiad (276/273 BCE), but this is hard to reconcile with Strabo's assertion that he studied in Athens with Zeno the Stoic, who died in 262/261 BCE. Around 246 BCE, Eratosthenes moved to Alexandria where he succeeded **Apollonius** as chief librarian. We are told he lived to be 80. According to the *Suda*, the next chief librarian, Aristophanes of Byzantium, was also his pupil.

There are very few remains of Erastosthenes' epic poem *Hermes* and of his elegy *Erigone*. His 12 books on ancient Attic comedy have been lost. The extant book *Katasterismos* (Star arrangements), which explains the mythological origin of the names of the constellations, is presumably an ancient abridgment of the work he wrote on the subject. According to R. Pfeiffer, Eratosthenes was the founder of critical chronology. In his lost *Chronographi* (Chronographies), he gave a full chronological survey of Greek history from the fall of Troy to the death of Alexander, based on the lists of Spartan kings and of Olympian victors. His precise reconstruction of the latter list, *Olumpionikai* (Olympian victories), is also lost.

Eratosthenes' contributions to mathematics included research on the duplication of the cube, and the famous sieve. The "sieve of Eratosthenes" was, until the recent invention of advanced computer programs, the only algorithm available for finding prime numbers. To find all primes smaller than a given integer N we write down the first N positive integers in order. We start then a sequence of operations, in each of which we cross out one or more integers, without deleting them. In the first operation, we cross out 1, which is not a prime. The first uncrossed integer is then the first prime, namely two; we leave it untouched and cross out every second integer from then on. After the second operation, the first uncrossed integer is the second prime, namely three; we leave it untouched and cross out every third integer from then on. (Some integers, like six and 12, will then be crossed out more than once.) And so on… After the nth operation, the first uncrossed integer is the nth prime, which we denote by $p(n)$. We leave it untouched and cross out every $p(n)$th integer from then on. The procedure stops as soon as the first uncrossed integer is greater than the square root of N (*e. g.*, after the 12th operation, if $N = 1{,}000$). At that stage, every uncrossed item in the list is a prime number $\leq N$.

Eratosthenes' method for measuring the circumference of the Earth is reported by **Cleomedes**. It rests on two idealizing assumptions: (1) The Earth is a perfect sphere and (2) the Sun is so far away that light coming from it reaches the surface of the Earth along parallel lines. Moreover, Eratosthenes incorrectly assumed (3) that Alexandria and Syene (today's Aswan) lie on the same meridian. On the summer solstice a pole planted vertically on the ground at Syene throws no shadow at noon. At Alexandria, on that same noon, a pole of the same height h similarly planted on the ground, makes a shadow of length l. From the ratio $h{:}l$ Eratosthenes could figure out the size of the angle α made by the vertical pole and the direction from which solar light fell on it in Alexandria. By assumptions (2) and (3) this direction is parallel to the direction of the solar light falling at that moment on Syene; hence, by assumption (1), angle α is equal to the difference in latitude between Syene and Alexandria.

If Syene and Alexandria both lie on the same great circle of a sphere of circumference equal to K, if Δ is the length of arc between them, and if the angle α subtended by this arc is expressed in degrees, then, evidently,

$$K = \frac{360\Delta}{\alpha}\,.$$

According to Cleomedes, Eratosthenes's calculations yielded $K = 250{,}000$ stadia. The quality of Eratosthenes' estimate depends of course on the actual length of one stadion. In classical Greece, it measured exactly 600 ft. The length of a foot varied from one city-state to another, but not by much, and Tannery suggests one stadion = 185 ± 5 m. Then, $K = 46{,}250$ km, a fair estimate of the circumference of the Earth. However, **Pliny** says that Eratosthenes counted 40 stadia per *schoenus*, an Egyptian unit that we know was equal to 630 km. Using this equivalence, we get $K = 39{,}375$ km, a figure eerily close to the actual length of a terrestrial meridian (≈39,942 km).

Roberto Torretti

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Erro, Luis Enrique

Born **Mexico City, Mexico, 6 January 1897**
Died **Mexico City, Mexico, 18 January 1955**

Diplomat and amateur astronomer Luis Erro was educated at Morelia, Michoacan, before he pursued eclectic studies in mathematics, civil engineering, history, and law. An outstanding public speaker, Erro first settled into business and political activities. Exiled from Mexico in 1923, he later returned as a director of technical education and was appointed an advisor to the Mexican presidency. Erro became enamored of amateur astronomy and specialized in the study of southern variable stars.

In the late 1930s, Erro served at first secretary of the Mexican Embassy at Washington, United States, where he came into contact with the American Association of Variable Star Observers [AAVSO], and the Harvard College Observatory. Erro convinced Mexican President Manuel Avila Camacho to provide support for a modern astrophysical observatory in his native land. Construction of the Observatorio Astrofísico de Tonantzintla [OAT] at Puebla began in 1941; the facility was dedicated on 17 February 1942. A 24- to 31-in. Schmidt telescope, with optics supplied by the Perkin – Elmer Corporation and mounting furnished by Harvard, was installed. Erro remained as director of OAT until his retirement in 1950; he was succeeded by **Guillermo Haro**.

Erro wrote *El pensamiento matemático contemporáneo* (Contemporary mathematical thought, 1944), and one novel, *Los pies descalzos* (Bare feet, 1951), which reflected his social opinions and broad personality. His country's first major planetarium, which was opened in México City in 1967, was named for Erro.

Jordan D. Marché, II

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Esclangon, Ernest-Benjamin

Born **Mison, Alpes de Haute-Provence, France, 17 March 1876**
Died **Eyrenville, Dordogne, France, 28 January 1954**

Ernest Esclangon is often remembered for his contributions to applied physics during World War I, and for his automated distribution of time signals by telephone.

Esclangon began his studies in a *collège* (school) in Manosque, his brother being a schoolmaster. He later attended the *lycée* (academy) in Nice before entering the École Normale Supérieure in Paris (1895). He received his degree in mathematics and secured a position at the Bordeaux Observatory in 1899 under **Georges Rayet**, which decided the fate of his career. There, Esclangon served as *aide-astronome* and *astronome adjoint*. While in Bordeaux, he taught courses in rational mechanics as well as in differential calculus.

In 1919, Esclangon became director of the Strasbourg Observatory. With help from **André Danjon**, he revived the institution in the postwar period. Esclangon then succeeded **Henri Deslandres** as director of the Paris Observatory in 1929, a position he held until his retirement in 1944. At both Strasbourg and Paris, he was simultaneously a professor of astronomy in the cities' universities. His teaching abilities were much appreciated by his students, and Esclangon remained open to new ideas.

The first research work performed by Esclangon was his doctoral dissertation (1904), which examined quasiperiodic functions. Introduced in 1893 by mathematician Piers Bohl, these functions proved particularly powerful in the case of Fourier series, producing a limited number of terms in their application. Esclangon perfected their theory, studied the corresponding differential equations, and established their usage in mathematical physics. This work constituted his main contribution to pure science, for which he was awarded the Grand Prix of the Académie des sciences.

Esclangon was also fond of the practical uses of mathematics, and his reputation was enhanced in two very different fields. Soon after World War I began, Esclangon proposed to the Service Géographique de l'Armée his idea of pinpointing the enemy's location by triangulating the sounds of artillery firings. Through field experimentation, Esclangon successfully constructed equipment that performed this task. General Ludendorff, head of the German staff officers, later argued in his memoirs that Esclangon's defensive device was one of the keys behind the victory of the Allied troops.

At the Paris Observatory, Esclangon responded creatively to an increasing demand from citizens to obtain the proper time by telephone. He created the first "talking" (*i. e.*, automatic self-announcing) clock. Esclangon broadcast the time through a series of photoelectric cells, which activated *pistes sonores* located on a rotating cylinder. The corresponding "blips" were issued from a synchronous clock, driven in turn by a fundamental clock at the observatory. The time service was inaugurated on 14 February 1933, and immediately the number of calls jumped to more than several thousand per day. The accuracy of the time provided on the telephone was better than 0.1 s.

During his lifetime, Esclangon published more than 200 papers on a variety of subjects, which included the mechanics of flight, acoustics, and relativity theory. Most of his publications were related to positional astronomy, instrumentation, and chronometry. Esclangon's last paper investigated the orbital mechanics of an artificial Earth satellite, several years before the Sputnik satellite was launched by the Soviet Union.

Esclangon's mathematical and scientific skills were called upon by various administrative agencies. His wartime contributions led to appointments as an attaché in the cabinet of the minister of the navy, along with an artillery commission. He later became a member of the Commission des inventions for the Centre National de la Recherche Scientifique. Esclangon was elected to the Académie des sciences in 1929 and to the Bureau des longitudes in 1932. He was made a *Commandeur de la Légion d'honneur*. Esclangon was elected president of the International Astronomical Union (1935–1938) following his organizing of its general assembly in Paris, and its participants were addressed by the President of France.

Esclangon lived in the village Eyrenville, where he owned a house in which he installed a water mill to provide electricity. He rode an old bicycle, which made such a noise that the citizens were preinformed of his arrival. They much appreciated Esclangon's kindness, simplicity, and the accuracy of his weather forecasts.

Jacques Lévy

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Danjon, A. (1955). "Ernest Esclangon." *Monthly Notices of the Royal Astronomical Society* 115: 124.

Espin, Thomas Henry Espinall Compton

Born **Birmingham, England, 28 May 1858**
Died **Tow Law, Durham, England, 2 December 1934**

Using 17- and 24-in. reflecting telescopes, the Reverend Thomas Espin discovered and measured 2,575 double stars and prepared catalogs of 3,800 red stars classified on the basis of his spectroscopic examination. As the son of Reverend Thomas Espinell and Elizabeth (*née* Jessop) Espin, he enjoyed a privileged childhood, was educated at Oxford, and entered the ministry of the Church of England. In 1888, at 33 years of age, he became Vicar of Tow Law, a position he held as a single clergyman for the remainder of his life. His scientific interests were broad, in common with many clergymen of his time, but his strongest interest was astronomy.

The appearance of comet C/1874 H1 (Coggia) in April 1874 stimulated Espin's earliest efforts in observational astronomy. It was not long after the event that he began contributing regular articles, signed T.E.E., to *The English Mechanic*, a practice he continued for most of his active career. At about the same time, the Prebendary **Thomas Webb** solicited Espin's help in gathering and editing information for a revision of Webb's *Celestial Objects for Common Telescopes*, an honor for the young observer. Espin continued to work with *Celestial Objects* after Webb's death, and eventually published a reedited and enlarged two-volume fifth edition (1893; reprinted 1905) of Webb's original book, which by then had become a standard work for amateur astronomers. In 1917 Espin updated a sixth edition of *Celestial Objects*.

Espin examined the stars listed in the *Bonner Durchmustrung* (Bonn survey) with a spectroscope of his own design using his large telescopes. With this approach it was possible to more reliably detect those stars with redder than normal colors. Espin gathered observations for a total of 3,800 red stars into several catalogs following the earlier examples of **Thomas Backhouse** and **John Birmingham**. In 1890, having carefully verified the colors given by others and after adding his own discoveries, Espin published the results as a sixth edition of Birmingham's catalog of red stars. The stars included in Espin's catalogs were generally too faint to appear in the Harvard catalogs of spectra, which added to the value of his work. Espin also recognized that many of the red stars he was cataloguing were variable; he is credited with the discovery of more than 30 new variable stars. The most noteworthy of his variable star discoveries was

Nova Lacertae, discovered in 1910. In his extensive survey, Espin measured and recorded the positions of 2,575 pairs of close stars.

With Webb as a mentor, a solid observing program, and an aggressive effort to publish his results in the *English Mechanic*, it should be no surprise that Espin was well known as an amateur astronomer. He was an active participant in several efforts to organize amateur astronomers in England. When the Liverpool Astronomical Society [LAS] was formed in 1881, Espin became an active member, along with **Isaac Roberts**, **William Denning**, Webb, **Thomas Elger**, and other well-known amateurs from the region. Espin was the second LAS president (1884/1885). When the LAS leadership recognized that overly enthusiastic members were reporting spurious observations as "discoveries," Espin volunteered to make confirming observations on short notice. However, his efforts led to conflicts over his methods of making attributions of the discovery priority and to other problems. When LAS ultimately failed, Espin became an active member of the British Astronomical Association.

Espin was a fellow of the Royal Astronomical Society. In 1913, he received its Jackson–Gwilt Medal for his discoveries of double stars and catalog of red stars as well as his Nova Lacertae discovery. He was elected to the International Astronomical Union Commission on Double Stars.

Thomas R. Williams

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Étable de la Brière, Nicole-Reine

➔ **Lepaute, Nicole-Reine**

Euctemon

Flourished **(Greece), *circa* 432 BCE**

Almost nothing is known of the Greek astronomer Euctemon, including his birth and death dates; it is known that he worked with the astronomer **Meton** in Athens around 432 BCE. This bit of information comes to us from **Ptolemy**, who mentions Meton and Euctemon. There is also a reference to Euctemon in Pausanius' *Description of Greece* as being the father of Damon and Philogenes, two Athenians who provided ships to the Ionians for their voyage to Asia. One reference indicates that Euctemon was wealthy enough to have craftsmen working for him.

Euctemon's chief astronomical contributions were largely in conjunction with those of Meton. They were reported to have developed a calendar of 365.25 + 1/76 of a day (30 min too long). A 19-year cycle was developed from an observation of the solstices since it was similar to observations made earlier in Mesopotamia, although the independent nature of the discovery is suspect. The Metonic cycle arises from 19 solar years, being almost exactly equal to 235 lunar cycles, and allows the prediction of eclipses. They also noted the inequality in the lengths of the seasons. Euctemon and Meton are also known for having introduced the parapegma, which was a tool used to associate the rising of a particular star and the civil calendar date. The parapegma was a stone tablet with movable pegs and inscriptions that allowed for such a calculation. A crater on the Moon is named for Euctemon.

Ian T. Durham

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Eudemus of Rhodes

Flourished **(Greece), 4th century BCE**

Eudemus was a student of **Aristotle** and an associate of **Theophrastus**. Like Theophrastus, he wrote a history of astronomy.

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Eudoxus

Born **Knidos (Tekir, Turkey), *circa* 390 BCE**
Died **Knidos (Tekir, Turkey), *circa* 338 BCE**

Eudoxus offered the first fully worked-out model of planetary motion.

Eudoxus was the son of Aiskhines of Knidos; he was probably born about 390 BCE, when Knidos was a Spartan ally and a closed oligarchy. Eudoxus was married and had three daughters, Aktis, Delphis, and Philtis; he died at the age of 52.

Eudoxus studied mathematics under **Archytas** of Taras and medicine under Philistion of Lokroi in southern Italy. He made astronomical observations there and in Sicily—perhaps around 361/360 BCE—when he may have been in Sicily.

Diogenes reports that Eudoxus came to Athens with little money at age 23, with his patron doctor Theomedon; he lived in the port, Piraeus, for 2 months, walking up to Athens daily for lectures at the academy. Around 366/365 BCE he sailed from Knidos to Egypt with **Chrysippus**, introduced by a letter from Agesilaus II of Sparta to Pharoah Nectanebo I. For over 1 year, Eudoxus remained in Heliopolis, near Cairo, studying language and religion with the priest Cho-nouphis, and making astronomical observations at nearby Kerkesoura. He also visited Memphis, where the priests predicted that his life would be short but famous (*endoxos*).

Geminus reports that Eudoxus wrote on the calendar, and some sources state that he wrote an *Octaeteris* (probably *circa* 365/364 BCE), which treated the 8-year cycle of the calendar, over which he perhaps distributed 49 months of 30 days and 50 months of 29 days in 8 Egyptian 365-day years. He is reported to have set the interval between autumnal equinox and winter solstice as 92 days, and that from winter solstice to spring equinox as 91 days; the other two intervals are not known but must sum to 182 days, and both were most likely 91 days (since Eudoxus later assumed uniform solar motion). This means that he ignored the earlier work of **Euctemon** and **Meton** on the inequality of the seasons, and on the 19-year luni-solar cycle. Eudoxus also gave seasonal weather and star-appearance data, preserved in the calendar appended to Geminus. It may also be at this time that he wrote *Disappearances*, which apparently treated the seasonal visibilities of stars. Eudoxus seems to have been the first to estimate the relative size of the Sun as many times larger than the Moon. (**Archimedes** records that he said "nine.")

Eudoxus visited Mausolos of Halikarnassos (modern Bodrum) around 364/363 BCE, and probably also visited his birthplace at this time. Knidos had relocated its site (from modern Datça to the better harbor at modern Tekir) around 365–360 BCE, and changed its constitution from oligarchic to democratic. Strabo records that Poseidonius claimed to have seen an observatory used by Eudoxus in new Knidos, but excavators have not identified it.

Then, around 363–357 BCE, Eudoxus taught at Cyzicus (modern Belkis), where his students included the mathematician brothers **Menaechmus** and Deinostratus of Prokonessos, and three natives of Cyzikos: Athenaius (not the much later mechanician), **Polemarchus** (the astronomer and teacher of **Callippus**), and perhaps **Helicon**. Besides mathematics and astronomy, he taught geography, metaphysics, and ethics. Probably during this period, Eudoxus composed his *Survey of Earth*, the astronomical works *Mirror* and *Phainomena*, as well as a work of mathematics.

Eudoxus's geography was the earliest to employ mathematical methods and the spherical Earth model. He covered "Asia" (the East), including Egypt, in Books 1–3, and "Europe" (the West), including Libya, in Books 4–6, with Islands (including Sicily and its Pythagoreans) in Book 7, telling ethnographic stories similar to those of Herodotus. He may be the author of the earliest extant estimate of the circumference of the Earth, 40 myriad stades (approximately 75,000 km), in **Aristotle**'s *On Heaven*.

The two works of descriptive astronomy, almost identical according to **Hipparchus**, were apparently based on observations made from a latitude where the longest day was about 15 hours (about 42° 2′ N), probably Cyzikos. They were the earliest systematic analysis of the sky, describing the constellations located along the celestial circles. Eudoxus's work was the foundation of **Aratus**'s poem *Phainomena*, and is described in Hipparchus's commentary thereon. Eudoxus located stars relative to parts of their figures, and sometimes clarified placements with geometry. He placed the solstitial and equinoctial points at the middle of the constellations Aries, Cancer, Libra, and Capricorn, possibly following the similar Babylonian practice, but he rejected their claims of predictive astrology. **Vitruvius** credits him with the invention of a type of sundial called the *arachnê* ("spider[-web]").

Eudoxus's mathematical work developed the theory of proportion presented in Euclid, Books 5 and 6, and the method of "exhaustion" (approach to the limit) presented in Euclid, Book 12. The former provided a definition of proportion applicable both to rational and irrational numbers (which D. Fowler suggests arose from his calendaric work); the latter provided a means to prove formulae for the area or volume of figures not tractable by Greek geometrical methods, such as the volume of the cone or pyramid.

Some years before 348 BCE, Eudoxus returned to Athens, accompanied by *many* students, and continued his research and teaching. (He did not join the academy.) He published his greatest astronomical contribution, the theory of concentric spheres, in *On Speeds*, probably after Plato's death, perhaps about 345–340 BCE. Attempts to reconstruct the lost work are rife with ambiguity, because we depend entirely on a brief report in Aristotle's *Metaphysics,* and a longer report in **Simplicius** that depends on the lost work *On Counter-rotating Spheres* of the 2nd-century astronomer **Sosigenes**, itself dependent on **Eudemus**'s lost *History of Astronomy*, Book 2. Eudoxus's books may not have survived the Roman conquest of Egypt.

The theory was a geocentric model of planetary motion, attempting to explain the movements of the seven planets (Sun, Moon, Mercury, Venus, Mars, Jupiter, and Saturn) on a common basis. Although probably not predictive, it contained numerical parameters based on observation. Each of the seven planets had three or four concentric rotating spheres whose axes were tilted with respect to one another, and whose compound motions explained the observed motion of the respective planet.

The outermost sphere of each planet moved with the same rotational velocity as the sphere of the fixed stars, *i. e.*, with a 1-day period, rotating from east to west. The second sphere rotated with its equator in the plane bisecting the band of the zodiac, from west to east, with "zodiacal" periods preserved by Simplicius (corresponding modern periods are given in the third column):

Saturn	30 years	29.45 years
Jupiter	12 years	11.86 years
Mars	2 years	1.88 years

(The periods of Venus and Mercury are not comparable.)

The Sun and Moon each had one more sphere, which rotated very slowly (the solar one east to west, and the lunar west to east), with its equator sufficiently inclined to the center of the band of the zodiac to explain the deviation of the Sun or Moon from that circle. Modern scholars usually suggest that Eudoxus must have intended a period of 1 month for the third lunar sphere, the second sphere being the very slow one (period about 18 or 19 years). A similar correction is often applied to the solar spheres, the third requiring a 1-year period, and the second a long period.

(Eudoxus did consider the Sun to have the small motion explained by the third sphere, as Hipparchus reports, quoting the *Mirror*: "the Sun differs in where it appears at the solstices." This geocentrically reasonable view was held by other Greek astronomers, but Hipparchus defined the center of the zodiac band as the ecliptic circle, on which the Sun traveled, thus rendering Eudoxus's third solar sphere otiose.)

Eudoxus took no account, and maybe had no knowledge, of the longitudinal variation in lunar velocity, and ignored the annual variation in solar velocity. (See above.)

Each of the other five planets had a total of four spheres, either to explain retrograde motion or the varying intervals of their phases of visibility. The third sphere's poles lay on the equators of the second spheres, those of Mercury and Venus coinciding, the others differing. These spheres rotated with synodic periods (the interval between corresponding position with respect to the Sun), evidently given to an accuracy of 1/3 month. Preserved by Simplicius they are as shown below:

Saturn	"close to 13 months"	378 days
Jupiter	"close to 13 months"	399 days
Mars	"8 months and 20 days"	780 days
Mercury	"110 days"	116 days
Venus	"19 months"	584 days

(The third column gives the corresponding modern average periods; the value for Mars is so discordant that scholars often amend the Greek to "8 months and 20.")

The fourth sphere carried the planet (on or near its equator), and rotated with the same period as, but oppositely and at an individual small inclination to, the third sphere. Their combined motion produced a figure-eight-shaped curve called by Eudoxus a *hippopedê*, and carried along the zodiac by the motion of the second sphere.

There were ancient objections to the theory's predictions of planetary latitude, and Polemarchus noted that it could not explain the variations in apparent lunar size or in the apparent brightness of Mars and Venus. **Giovanni Schiaparelli**'s reconstruction of Eudoxus' model could not match the observed retrograde motion of Venus or Mars (with either period), but our evidence possesses enough gaps to allow various interpretations, some of which generate motions very close to the observed.

Eudoxus' planetary theory accounted for most of the easily observed phenomena of all seven planets, and though modified by Callippus, Aristotle, and **Autolycus**, was not superseded for almost four generations (by **Apollonius**). The qualitative nature of the model colored astronomical thinking through **Ptolemy** (who spoke of planets as carried-on segments of spheres), and thus through the era of **Johannes Kepler**. When ancient or medieval astronomers wrote of the harmony of the spheres, it was to these spheres that they referred (though Eudoxus himself did not subscribe to the notion).

Paul T. Keyser

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Euler, Leonhard

Born **Basle, Switzerland, 15 April 1707**
Died **Saint Petersburg, Russia, 18 September 1783**

Leonhard Euler made major contributions to celestial mechanics and spherical astronomy, as well as to mathematics and physics.

Leonhard's father, Paulus Euler, was a Protestant minister and married Margaretha Brucker in 1706. The family moved to the village of Riehen, near Basle, where Euler spent his childhood. In 1720 he joined the Department of Arts of the University of Basle, where he received the *prima laurea* (bachelor) in 1722. One year later Euler received the master's degree in philosophy, which was on comparing the world systems and theories of gravitation of **René Descartes** and **Isaac Newton**. In 1723, he joined the Department of Theology, but devoted most of his time to mathematics. Euler was given the opportunity to attend private lectures by **Johann Bernoulli**, who recognized Euler's extraordinary potential in mathematics. At the age of 18, Euler began his own investigations on mechanics and mathematics. He left Basel in 1727 to accept an invitation of the newly organized Saint Petersburg Academy of Sciences. There he became professor of physics in 1731 and succeeded **Daniel Bernoulli**.

At the young Russian academy, Euler was surrounded by first-rank scientists, such as Jakob Hermann, Bernoulli, Christian Goldbach, and the astronomer and geographer **Joseph Delisle**, who introduced him to the current problems in theoretical, observational,

and practical astronomy. In 1733 Euler married Katharina Gsell, and in 1734 Johann Albrecht was born, the first of their 13 children.

Following an invitation from Frederick the Great of Prussia, Euler moved to Berlin with his family in 1741. He was appointed director of the mathematical class of the academy, and deputy of the academy's president, **Pierre de Maupertuis**. After Maupertuis's death in 1759, Euler continued presiding over the academy, although without the title of president. During this period, he considerably broadened the scope of his investigations and, competing with **Jean d'Alembert, Alexis Clairault**, and D. Bernoulli, laid theoretical foundations of mathematical physics and astronomy.

Conflicts with King Frederick caused Euler to leave Berlin in 1766, and to return to the Saint Petersburg Academy, with which he had kept regular working contacts. Together with his son Johann Albrecht, Euler was a member of the commission in charge of the management of the academy in 1766. Illnesses in 1738 and 1766 had damaged his eyesight, and by 1771 he was completely blind. Yet his blindness did not lessen his scientific activity.

Euler was a member of the academies of sciences of Saint Petersburg (1731), Berlin (1746), and Paris (1755), and was a fellow of the Royal Society of London (1746). He died of a brain hemorrhage.

Euler's astronomical works address three fields of research: celestial mechanics, spherical astronomy and astronomical geodesy, and geo- and astrophysics ("cosmical physics"). His main interests, however, were focused on celestial mechanics.

Euler developed the theory of the motions of two bodies in his *Mechanica*, published in 1736, which he considered not only as an introduction to celestial mechanics, but as the foundation of all mechanics as well. The novelty of this book is the use of analysis rather than geometry to describe mathematically the free and constrained motions of point-like masses in empty space as well as in resisting media. Euler studied the motion of a particle around a central body when subjected to a central force (Keplerian motion). An important application concerns the determination of the orbits of planets and comets. Stimulated by the appearance of two great comets in 1742 and 1744 (C/1742 C1 and C/1743 X1), Euler developed new methods to determine the (elliptical) orbits of planets and the (parabolic) orbits of comets.

Euler wrote several treatises on the mutual perturbations of celestial bodies due to the inverse-square law of gravitation (perturbation theory), usually assuming the accelerations or perturbative forces as given and developing their effects on the orbital elements. He tried to solve the general problem of perturbation analytically, in particular the general problem of three bodies. He found solutions for special cases, which he called "restricted three-body-problems." Euler applied these theories to four main astronomical problems that could be solved (at least approximately) by such theories: (1) the theory of the motion of the planets around the Sun, in particular the inequalities in the respective motions of Jupiter and Saturn (Great Inequality), (2) the motion of the barycenter of the Earth–Moon system around the Sun, considering gravitational interactions of the planets, (3) the motion of the Moon around the Earth, and (4) the rotation and figure of the Earth (luni–solar precession and nutation). For the latter two problems both the Earth and Moon had to be treated as extended rigid bodies. Euler's best-known discovery is the famous equations describing the rotational motion of rigid bodies, which appeared (with respect to an inertial frame of reference) for the first time in 1752. He finished the theory of the motion of rigid bodies in 1765. The "Eulerian equations" with respect to a body-fixed coordinate system also appeared for the first time in 1765. He found special solutions of these equations, in particular in the absence of external torques (Eulerian free nutation). These studies on rigid bodies obviously stimulated Euler in 1759 to develop the theory of the two- and three-body problem applied to rigid bodies.

For Euler, empty space was not an acceptable idea. He postulated instead the existence of an omnipresent, extremely thin and subtle continuous "matter," characterized by an extremely high elasticity and an extremely low density. This medium is Euler's ether, and he derived gravity from ethereal pressure. Euler also used this model to explain secular effects in the motions of the Moon (secular acceleration) and the planets (long-time variations of the orbital elements, *e. g.*, gradual shrinking of orbits) caused by ethereal resistance. But this model was not sufficient to explain all inequalities, particularly the motion of the Moon's apogee. In this case, Euler questioned the validity of the inverse-square law, and formulated and used (in several of his treatises) the law of attraction in a more general way. When Clairault "proved" the correctness of the inverse-square law in the case of the apsidal motion of the Moon in 1750, this matter was definitely settled.

The earliest published astronomical tables incorporating perturbations deduced analytically from the inverse-square law of gravitation appear to have been Euler's *Novae et correctae tabulae ad loca lunae computanda* and *Tabulae astronomicae solis & lunae*, published in 1745 and 1746, respectively.

Euler developed the formulae of spherical trigonometry and used them for transformations of celestial coordinates, probably inspired by his own studies on the theory of rotation of celestial bodies. He contributed to the reduction of astronomical observations by developing new methods for the determination and calculation of effects such as precession, nutation, aberrations, parallaxes, and refractions, which must be considered when processing astrometric observations of the positions of celestial bodies. Moreover, Euler was aware of the fact that his solar, lunar, and planetary theories could be modeled with sufficient accuracy only by using observations that were reduced correctly. Some of his papers are therefore devoted to the determination of astronomical constants associated with these effects. Euler developed a new and general processing method for the estimation of the solar parallax by transits of Venus, and determined a value that is very close to the present-day value.

Euler wrote several papers on the physical constitution of celestial bodies (mainly on comets) as well as on celestial and terrestrial phenomena related to the Earth's atmosphere or its magnetic field. Most prominent is his theory on the physical cause of comet tails, of the northern lights, and of the zodiacal light, which he tried to explain by one and the same physical process.

Euler's memoir published in 1752 may be regarded as one of the first studies on photometric astrophysics. He developed a theory of the intensities of illuminations of celestial bodies for stars, planets, and satellites. Euler then tried to determine the distances and physical constitutions of these bodies from their apparent brilliances, and found that "the material of the Sun has to be totally different from any burnable matter on Earth, and that it must be in such a state of heating as no body on Earth could ever be."

Andreas Verdun

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Eutocius

Flourished **(Israel), *circa* 500**

Eutocius is cited as the author of an introduction to the *Almagest*. But most scholars doubt that this work ever existed.

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Evans, David Stanley

Born **Cardiff, Wales, 28 January 1916**
Died **Austin, Texas, USA, 14 November 2004**

In a career that took him to three continents, David Evans made his mark in several fields of observational astronomy including photographic and spectrographic studies of planetary nebulae and galaxies, stellar photometry, spectroscopy, and high-speed photometric studies of transient astronomical events. His later career included valuable historical studies.

Evans attended the Cardiff High School for Boys until 1932, and then entered King's College, Cambridge, in 1934 as a major scholar. In 1938 he transferred to Oxford University where, under the direction of **Arthur Eddington** and **Richard van der Riet Woolley**, he obtained his Ph.D. in astrophysics in 1941 with a dissertation on the formation of the hydrogen Balmer line spectrum in stellar atmospheres. During World War II, Evans worked as a medical physicist. From 1941 to 1946 he also served on the editorial board of *The Observatory*.

In October 1945 Evans was appointed second assistant at the Radcliffe Observatory, Pretoria, South Africa, arriving there in early 1946. Working only with untrained laborers, he modified the mirror cell and installed the primary mirror of the 74-in. telescope in 1948. The mirror had arrived 10 years after the mechanical parts and was thinner than anticipated. Since the Newtonian configuration was the only one available at first, Evans undertook a program of photographic astronomy and photometry of southern galaxies and planetary nebulae. The pioneering *Cape Photographic Atlas of Southern Galaxies* was one result of this work. When spectroscopic equipment designed by Evans for especially high photographic speed became available, Evans obtained the first redshifts measured for brighter southern galaxies with the partial collaboration of Stuart Malin.

Early in 1951 Evans joined the Royal Observatory, Cape of Good Hope, as chief assistant and was in charge of the Cape share, amounting to one-third of the observing time on the 74-in. telescope, following an agreement between the British Admiralty and the Radcliffe Trustees. This observing time was devoted to spectral classification and radial velocity studies of stars whose parallaxes had been measured at the Cape.

During the early 1950s, Evans and others recognized that a unique series of lunar occultations of Antares and Aldebaran, events that occur on a 19-year cycle, would provide an opportunity to attempt measurements of the angular diameters of these stars. Using conventional photometric techniques, five successful observations were obtained of the occultation of Antares. Evans analyzed the data from these occultations and concluded that Antares was possibly nonspherical or severely spotted. Although Evans's results were met with skepticism at the time, his analysis has been vindicated by interferometric measurements as well as by later occultation studies.

Evans was instrumental in the selection of the Sutherland site for what became the South African Astronomical Observatory.

Evans spent the academic year 1965/1966 as a senior visiting scientist fellow at the University of Texas. On 4 October 1968 he resigned from the Royal Observatory, where he had reached the civil service rank of senior principal scientific officer, to become a professor of astronomy and associate director for research at the University of Texas at Austin and at the McDonald Observatory. His research included further development of the high-speed photometric occultation technique for determining stellar diameters, the use of precise time-resolution techniques in flare star studies, and the application of a star spot model to certain variable M-dwarfs.

The cosmic distance scale is based on knowledge of the luminosities of Cepheid variables. One way of obtaining the luminosities involves determining their radii. From Evans's work on stellar diameters, and that of Thomas G. Barnes on near-IR photometry, it was found in 1976 that a simple relationship exists between the surface brightness of a star and its color in the V–R color index. The Barnes–Evans relationship can be used to determine the radii and distances of pulsating stars by means of light, color, and radial velocity measurements during the pulsation cycle. This technique is an evolutionary development of the Baade–Wesselink method.

While residing in South Africa, Evans took an interest in the history of astronomy that continued uninterruptedly since that time. His interest in **John Herschel** sparked his first historical project on Herschel's experiences at the Cape. Since then, Evans wrote the only extant biography for the Abbé **Nicolas de Lacaille**, another astronomical visitor to the Cape, and then a general history of astronomy in the Southern Hemisphere (*Under Capricorn*). Later he collaborated in a history of the McDonald Observatory after arriving in Texas. He also edited several volumes of symposium proceedings. At Oxford University, he was for several years scientific editor of the journal *Discovery* – now merged with the *New Scientist*.

In September 1984 Evans was named as the first Jack S. Josey Centennial Professor in Astronomy by his colleagues and the University of Texas Board of Regents. A symposium was held in Evans's honor at the University of Texas on 18–19 September 1986, when he became emeritus professor.

Evans received the Tyson Medal (1937) and a Rayleigh Prize (1938) from Cambridge University, and the Macintyre Award for Astronomical History (1972) and the Gill Medal (1988), both from the Astronomical Society of Southern Africa. On retirement, he and his wife were made honorary citizens of Texas by the state's Governor.

On 8 March 1949 Evans married Betty Hall Hart. They have two children, Jonathan Gareth Weston Evans and Barnaby Huw Weston Evans.

Ian S. Glass

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Evans, John Wainright

Born **New York, New York, USA, 14 May 1909**
Died **Santa Fe, New Mexico, USA, 31 October 1999**

John Evans was the first director of the United States Air Force's Sacramento Peak Observatory [SPO] (later part of the National Solar Observatory). From the Sudanese desert, his 1952 SPO eclipse expedition produced spectra that revealed the temperature and density of the chromosphere as a function of height.

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Evershed, John

Born **Gomshall, Surrey, England, 26 February 1864**
Died **Ewhurst, Surrey, England, 17 November 1956**

English solar astronomer John Evershed is remembered largely for the discovery of the effect that bears his name, the radial outflow of gas in sunspots at a speed not much more than 1 km s^{-1}. Evershed was the seventh child of John and Sophia (*née* Price) Evershed. He was educated at schools in Brighton and Croydon. Toward the end of his life Evershed recalled his scientific curiosity first being aroused by a partial solar eclipse. At age 13 he built a small telescope to observe Mars during its favorable 1877 opposition. His brother Sydney introduced him to professional scientific circles, and as a young man he met Charles Darwin and **Alfred Wallace**. Evershed developed an interest in lepidoptera and other insects, but studying the Sun was to be his lifelong passion. The friendship of **Arthur Ranyard** proved especially influential in this regard. Ranyard introduced Evershed to **George Hale**, and he bequeathed Evershed his 18-in. reflecting telescope.

Between 1890 and 1905 Evershed made a long series of observations of solar prominences from his private observatory at Kenly. During this period a manufacturing firm employed him in the analysis of oils and other industrial substances. The company granted Evershed leave to join the British Astronomical Association solar eclipse expeditions to Norway in 1896 and India in 1898. The 1896 eclipse was clouded out, but on the expedition Evershed met his future wife, Mary Acworth Orr (**Mary Evershed**). The 1898 eclipse was more of a scientific success. At the beginning and at the end of the eclipse, Evershed observed the "flash" spectrum of emission from gas that would normally be a source of absorption features when light from the solar photosphere passes out through it, and showed that the spectral features had essentially the same pattern in emission as in absorption. In addition, he obtained the first photograph showing that the continuous (reflected) light from the corona extended blueward of the Balmer limit at 3646 Å. For the 1900 eclipse in Algeria, Evershed chose a site near the southern limit of totality, because from this vantage point the duration of the "flash" was increased. Although his site was actually south of the limit, he again obtained valuable data.

The eclipse results were published by the Royal Society and led to an acquaintance with Sir **William Huggins**. It was through the recommendation of Huggins that the India Office appointed Evershed assistant to C. Michie Smith at the Kodaikanal Observatory in 1906. In 1911 he succeeded Smith as the director of the observatory. Much of his work at Kodaikanal was on the spectrum of sunspots. In 1909 Evershed first measured the Doppler shifts of umbral and penumbral gases moving radially outward from a sunspot. The phenomenon came to be known as the Evershed effect. In addition to his solar work, Evershed obtained spectra of Halley's comet (IP/Halley), Nova Aquilae 1918, and dark clouds in the Milky Way. Also during his stay in India, Evershed set up a temporary observing station in Kashmir (where he found exceptionally good observing conditions) and served as an advisor on the establishment of an observatory in New Zealand. It was from Kashmir that Evershed obtained a 1915 spectrogram of the Sun that he concluded might marginally show the predicted Einsteinian gravitational redshift of solar absorption lines. The expected shift is rather less than either the Evershed flow or the convective velocities in the solar atmosphere, and what he observed was clearly a mix of the three effects, which have only rather recently been sorted out. He retired from Kodaikanal in 1923, returned to England, and established a private observatory at Ewhurst. Work carried out during these later years included consultation with Hale on the Sun's magnetic field, and continuing studies of solar rotation. Evershed finally closed his observatory in 1953, when he was 89 years old.

Evershed was a founding member of the British Astronomical Association. He served as director of the solar spectroscopy section in 1893–1899 and director of the spectroscopy section in 1924–1926. In 1915 Evershed was elected a fellow of the Royal Society; 3 years later he received the Gold Medal of the Royal Astronomical Society. Upon his retirement from Kodaikanal, Evershed was made a Companion of the Indian Empire.

Evershed was an instrumentmaker at heart. All of his eclipse equipment was homemade. He also designed a spectroheliograph independent of Hale's invention of the instrument. At Kodaikanal, Evershed built a high-dispersion spectrograph and a spectroheliograph for photography in hydrogen light. At Ewhurst he experimented with large hollow prisms filled with ethyl cinnamate to increase the resolution of spectrograms.

In 1906 Evershed married Mary Orr. She was a loving companion and an active collaborator of his observational programs, as well as the author of *Dante and the Early Astronomers* and *Who's Who in the Moon*. She died in 1949. In 1950 Evershed married Margaret Randall. There were no children.

Keith Snedegar

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Evershed, Mary Ackworth Orr

Born **Plymouth Hoe, Devon, England, 1 January 1867**
Died **Ewhurst, Surrey, England, 25 October 1949**

British solar physicist, historian of astronomy, and Dante Alighieri scholar Mary Evershed made important contributions to observations of solar prominences and their classification, with some, but not all, of the work done in collaboration with her husband **John Evershed**. The work resulting in the discovery of what is now called the Evershed effect (horizontal flow of gas in the penumbrae of sunspots) was done by John Evershed early in their marriage.

She was born Mary Ackworth Orr, a daughter of Andrew Orr, an army officer (who died when Mary was only 3 years old) and his wife Ruth. After the father's death, the children were brought up by their mother in the home of their clergyman grandfather, in a vicarage near Bath. Mary and her sister Lucy received their education entirely at home from an enlightened governess who, when Mary was 20, took the sisters abroad to study languages and the arts in Germany and Italy. They spent the years 1888–1890 in Florence where Mary became fascinated by the work of the poet **Dante Alighieri** and particularly by the astronomical references that abound in his *Divine Comedy*. After this period of study, the family moved to Australia, living near Sydney for 5 years.

During this time Mary developed her knowledge of astronomy, encouraged by **John Tebbutt**, the well-known amateur astronomer and comet discoverer who was Australia's leader in the field at the time. The result was *An Easy Guide to the Southern Stars* (1897; second edition: 1911), a small atlas intended for beginners containing maps of recognizable naked-eye stars and star groups visible from the latitude of Australia.

On returning to Britain, Mary became an active member of the recently founded British Astronomical Association. She settled in Frimley, Surrey, and acquired a 3-in. (7.6-cm) refractor with which to make serious observations of double and variable stars. She also took part in the association's eclipse expeditions to Finnmark and Algiers. On the first of these, in 1896, she met John Evershed whom she would marry.

John Evershed, an amateur astronomer who specialized in solar spectroscopy and had built a number of excellent spectroscopes, had in 1892 constructed a spectroheliograph according to the design of its inventor, **George Hale**. John was soon recognized as one of the leading practitioners of solar spectroscopy. In 1906 he was offered a professional appointment as assistant astronomer at the Observatory at Kodaikanal in India. In that year he and Mary were married and traveled to India by way of the United States and Japan. John took up his appointment in 1907 and in 1911 was made director of the observatory when that post fell vacant. The Eversheds remained in India until his retirement in 1923. The Eversheds had no children, but Mary's nephew, **Andrew Thackeray**, stimulated by their example, became an astronomer and director of the Radcliffe Observatory in Pretoria, South Africa.

Though not an official member of staff, Mary gave valuable assistance to her husband on various astronomical missions, including site-testing expeditions to Kashmir and New Zealand and an eclipse expedition to Australia in 1922 (which was, however, frustrated by the weather). In the observatory, she made herself familiar with spectroheliograph work, her special interest being solar prominences. In 1913 she published a substantial paper in the *Monthly Notices of the Royal Astronomical Society* (read in person at a meeting of the society when the Eversheds were in London on leave) in which she analyzed records of prominences associated with sunspots made between 1908 and 1910. She was able to classify these as active and eruptive, and to track their motions from photographs taken at brief intervals, thus anticipating cinematography with the coronagraph later. Mary pursued the same research in a joint paper with her husband, published in 1917 by the Kodaikanal Observatory. The analysis was principally hers, and involved almost 60,000 individual prominence observations covering an entire sunspot cycle.

During her years at Kodaikanal, which she found an ideal place to write on astronomy and poetry, Mary also pursued her studies of Dante Alighieri, which culminated in her book, *Dante and the Early Astronomers* (1914), published under the name, "M. A. Orr (Mrs. John Evershed)." There she demonstrated the poet's considerable knowledge of the astronomy and cosmology of his day, and elucidated the astronomical allusions in the *Divine Comedy* that he used to indicate date, hour, or passage of time. These references are largely obscure and require knowledge of astronomy as well as classical and historical sources. The *Divine Comedy* is an account of the poet's imaginary journey through Hell, Purgatory, and Heaven, which takes place over a fixed period of time. Mary's account of this journey, based on its scientific references, was described by Dorothy Sayers, a well-known translator of the poem, as "quite the best guide available to Ptolemaic astronomy and to Dante's handling of celestial phenomena." A second edition of the book, revised by the Dante Alighieri scholar Barbara Reynolds, appeared in 1956, some years after the author's death.

The Eversheds retired to England in 1923. Mary now devoted her energies to the British Astronomical Association. She founded and became head of the association's historical section, contributing numerous charming articles to its *Journal*.

The most ambitious of Mary's historical projects was the compendium *Who's Who in the Moon*, edited by her, a directory identifying every person named in the lunar formations. For this task she enlisted the help of a team of astronomers from Britain and abroad. This fascinating directory is currently (2002) being revised.

Mary Evershed died of cancer at her home in Surrey.

Mary T. Brück

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Ezra

➜ **Ibn ʿEzra: Abraham ibn ʿEzra**

F

Fabricius, David

Born **Esens, (Niedersachsen, Germany), 9 March 1564**
Died **Resterhave, (Niedersachsen, Germany), 7 May 1617**

David Fabricius is remembered today as the discoverer of the long-period variable star Mira in the constellation of Cetus.

David Fabricius was a Lutheran clergyman who pursued interests in astrology, astronomy, and cartography on a highly sophisticated level. The son of a smith, Fabricius attended Latin school in Braunschweig, where he studied mathematics and astronomy with Heinrich Lampe. Fabricius entered the University of Helmstadt in 1583 to study theology, and shortly thereafter established a home with his new wife in the East Frisian village of Resterhave.

In 1596, while observing Jupiter in the constellation of Cetus, Fabricius discovered the variable star Mira Ceti. He later wrote several tracts on this discovery, comparing its significance with the supernova of 1572. Having initiated a correspondence with **Tycho Brahe**, Fabricius visited Brahe in Wandsberg in 1598. Fabricius soon became thoroughly familiar with Brahe's observational methods and planetary system. In May 1601 Fabricius visited Brahe a second time, in Prague.

Fabricius befriended **Johannes Kepler** through frequent correspondence following the death of Brahe in October 1601. Kepler considered Fabricius to be Europe's finest observational astronomer. But Kepler grew impatient with Fabricius' loyalty to the Tychonic system and his opposition to physical astronomy, and finally broke off their correspondence in November 1608. Fabricius' many other astronomical correspondents included **Willem Blaeu**, Johannes Erikson, **Simon Mayr**, and Matthias Seiffart. David's son **Johannes Fabricius**, is considered today to have been the first to discover sunspots and, consequently, the rotation of the Sun, in 1611.

A local parishioner whom Fabricius had recently admonished from the pulpit struck down Fabricius with a blow to the head. Fabricius was father to eight children.

Patrick J. Boner

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Fabricius, Johann

Born **Resterhave, (Niedersachsen, Germany), 8 January 1587**
Died **19 March 1616**

Johann Fabricius was one of the first astronomers to observe sunspots with a telescope, and the first to publish an account of his observations.

Fabricius was the eldest son among the seven children of famed astronomer, astrologer, and Lutheran Pastor **David Fabricius**. Johann first studied medicine, mathematics, and astronomy at the University of Helmstedt in 1605, and then enrolled at Wittenberg University the following year. In December 1609 he moved on to Leiden University, where he matriculated as a student of medicine, but was eventually awarded a *Magister Philosophiae* degree in September 1611.

While in Leiden, sometime near the end of 1610, Fabricius acquired one or more telescopes, which he brought home to his father's house in Osteel. Already well aware of the astronomical potential of the telescope from **Galileo Galilei**'s *Sidereus Nuncius*, the father-and-son team began telescopic observations, on the lookout for something new. Johann first noticed sunspots at sunrise on 9 March 1611 (27 February on the Julian calendar then still in use in East Frisia), and for many weeks following was engaged with his father in daily observations whenever the weather permitted. Most of their observations were carried out *via* the *camera obscura* technique, which consists of forming a projected image of the Sun through a pinhole opening into a suitably darkened room. They had first observed the Sun directly through the telescope, a harrowing experience that Johann later related in his *Narratio*:

> Having adjusted the telescope, we allowed the sun's rays to enter it, at first from the edge only, gradually approaching the center, until our eyes were accustomed to the force of the rays and we could observe the whole body of the sun. We then saw more distinctly and surely the things I have described [sunspots]. Meanwhile, clouds interfered, and also the sun hastening to the meridian destroyed our hopes of longer observations; for indeed it was to be feared that an indiscreet examination of a lower sun would cause great injury to the eyes, for even the weaker rays of the setting or rising sun often inflame the eye with a strange redness, which may last for two days, not without affecting the appearance of objects.

In June 1611, Fabricius published a small pamphlet printed at Wittenberg, describing his sunspot observations. The work is entitled *de Maculis in Sole observatis et apparente earum cum Sole conversione, Narratio* (Account of spots observed on the Sun and of their apparent rotation with the Sun), and was sold at the Frankfurt Book Fair the following autumn.

In his *Narratio*, Fabricius correctly identified the spots as belonging to the Sun. On the basis of the varying shape and apparent speed of these spots as they move across the solar disk, he also correctly interpreted his observations as indicating an axial rotation of the Sun. Fabricius was already aware of the latter idea being a theoretical possibility, from the writings of **Johannes Kepler**, who in his 1609 *Astronomia Nova* had postulated solar rotation as the magnetically mediated motive force responsible for planetary orbital motion.

Practically nothing is known of the final 5 years of Fabricius' life. In a few surviving letters to Kepler, he affirmed his dedication to astronomy, and announced a method for weather prognostication of unprecedented reliability. Following his death, and that of his father, the young Fabricius was rapidly eclipsed in the priority controversy then flaring between Galilei and the Jesuit **Christoph Scheiner** over the discovery of sunspots. In their writings, both Kepler and **Simon Mayr** attempted to establish Fabricius' precedence on the topic, but to no avail. It was only in 1723, following the discovery of a copy of his 1611 pamphlet, that Fabricius' remarkable deductions regarding sunspots and solar rotation were once again brought to the attention of the astronomical world.

Paul Charbonneau

Alternate name

Goldsmid, Johann

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Wattenberg, Diedrich (1964). *David Fabricius: Der Astronomen Ostfieslands*. Berlin-Treptow: Archenhold-Sternwarte.

Fabry, Marie-Paul-Auguste-Charles

Born **Marseilles, France, 11 June 1867**
Died **Paris, France, 11 December 1945**

Interferometrist Charles Fabry was the fourth of five sons born to Auguste Charles Fabry and Léontine Claire Marie Estrangin. Like his father, grandfather, and two of his brothers, Fabry studied at the École Polytechnique in Paris, from which he graduated in 1888. He received his *Agrégation* in 1889 and doctorate in the physical sciences in 1892, both from the University of Paris. On 7 May 1900, Fabry married Claire Marguerite Marie Berthe Buser; the couple was childless.

While still a student, Fabry expressed an interest in optics, and his physics professor at the École Polytechnique, **Alfred Cornu**, advised him to join the laboratory of Jules Macé de Lépinay, physics professor at Marseilles University and a specialist in optical interference. After completing his studies, Fabry returned to his native city, taking up the post of *Maître de Conférence* (lecturer) at the Marseilles Faculty of Sciences in 1894, becoming professor of physics there upon Macé's death in 1903. In Macé's laboratory, Fabry met Jean Baptiste Gaspard Gustav Alfred Perot, professor of industrial physics as well as a graduate of the École Polytechnique, and the three men began collaborating on the investigation of interference phenomena. Although carried out in a physical laboratory, these researches were aimed to supply metrological, astronomical, physical, and meteorological applications, in the French tradition of physical optics going back to Augustin Fresnel and **Dominique Françoıs Arago**.

In particular, Fabry and Perot developed in 1897 a new device, the multibeam interferometer, which enabled the measurement of lengths in terms of wavelengths, or reciprocally, of wavelengths in terms of lengths (metric units). This device provided the basis for Fabry and Perot's program of research in the following decades. Most notably, they used the interferometer to measure the standard meter in wavelengths of the red cadmium line in 1907, a measurement that confirmed **Albert Michelson**'s interferential measurement of the same in 1892, and opened the possibility of indexing the meter in terms of a wavelength scale rather than defining a metal bar. Fabry and Perot also used this measurement, understood in absolute metric terms, to criticize **Henry Rowland**'s table of solar spectral wavelengths, then the current spectroscopic standard in astrophysics.

Fabry and Perot convinced the newly created International Union for Cooperation in Solar Research of the necessity of using their interferometer and a laboratory spectrum (rather than the Sun) to establish the scale of wavelengths. This task was undertaken by the union after 1907, and completed by its successor institution, the International Astronomical Union. Fabry and Perot thus brought astrophysical spectroscopic practices in line with the metric system and helped standardize astrophysical practices internationally. Both Fabry and Perot subsequently pursued physical as well as astrophysical investigations using the multibeam interferometer. Perot's later research was conducted at the Meudon Observatory after 1908, while Fabry left Marseilles in 1920, becoming professor at the Sorbonne (1921) and director of the Institut d'Optique (1922) as well as professor of physics at the École Polytechnique (1927).

Fabry was elected a member of the French Académie des sciences and several other French and foreign scientific societies, including the Société française de physique, the Royal Institution of London, the Franklin Institute, the Royal Society of London, and the Royal Astronomical Society of London. He was made an *Officier de la Légion d'honneur* in 1923 for his wartime service as head of the Physical Section of the Service of Inventions. Fabry received several scientific awards including the Janssen Prize (1918), the Draper Medal of the National Academy of Sciences (1919), and the Franklin Medal of the Franklin Institute. He was nominated several times, albeit unsuccessfully, for the Nobel Prize in Physics.

Besides his interferometric and metrological work, Fabry's contributions in the domain of astronomy include studies of the solar spectrum, especially in the ultraviolet; of the Doppler effect; and of visual and photographic photometry. (He was a member of the Commission Internationale de l'Éclairage and participated in the elaboration of photometric standards). He also studied the luminosity of nocturnal skies, atmospheric ozone, and physical and instrumental optics. Fabry produced more than 300 publications, chiefly in the *Annales de Physique et de Chimie* and the *Comptes rendus hebdomadaires des Séances de l'Académie des Sciences*.

Charlotte Bigg

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Fallows, Fearon

Born **Cockermouth, (Cumbria), England, 4 July 1789**
Died **Cape Town, (South Africa), 25 July 1831**

Fearon Fallows, a mathematician by training, was appointed as the director of the Royal Cape Observatory in South Africa, but died prior to being able to accomplish a great deal as an astronomer. Fearon Fallows was born to John Fallows (died: 1826), a weaver, and Rebecca Fallas (died: 1828). Fallows was born literally next door to "Wordsworth House," mansion-house birthplace of the famous Romantic poet William Wordsworth, though it is unlikely the two ever met; a commemorative plaque mounted on Fallows's cottage wall incorrectly states the year of his birth as 1788. Fallows was initially tutored at home by his father, and then sent to a private mathematics tutor, Mr. Cooper, at the nearby village of Brigham. Various other private tutors followed.

In 1809, Fallows began to study mathematics at Saint John's College, Cambridge, paid for by local benefactors and supporters. He entered Saint John's College at the same time as fellow astronomers **John Herschel** and George Peacock, and graduated as third wrangler in 1813, behind Herschel and Peacock. After his graduation, Fallows spent several years lecturing on mathematics at Corpus Christi College, Cambridge; in 1816, he became an examiner, and in 1818, moderator (chief examiner) of mathematics, Saint John's College. Around that time, he took orders in the Church of England. Fallows married Mary Anne Hervey, daughter of Reverend H. A. Hervey (one of Fallows's tutors and supporters), on 1 January 1821. All of their known offspring died at an early age at the Cape of Good Hope, where Fallows himself died, probably of scarlet fever; he is buried on the Royal Cape Observatory grounds.

Fallows was elected as a member of the Astronomical Society of London in 1820. Despite having almost no practical astronomical observing experience, Fallows was selected on 26 October 1820 by the British Admiralty Board to travel to the Cape of Good Hope, South Africa, to establish an astronomical observatory, and take the position as its director. There, his task was, among other things, to map the southern stars, to attempt to rediscover a comet last seen in 1819, and to make observations capable of improving the current theory of atmospheric refraction. Fallows accepted, and was given the title "His Majesty's Astronomer." Fallows picked up much knowledge through observatory visits and correspondence prior to his departure.

On 4 May 1821, Fallows and his wife started out for Cape Town, where they arrived on 12 August. There, he selected the site for the establishment of the Royal Observatory at Slangkop (Snake Hill), at the confluence of the Liesbeek and Black rivers, and oversaw its construction. From the start, Fallows was frustrated by bureaucracy, wrangles over land rights, lack of good quality instruments and support staff, poor support from the Admiralty back in England, and more, including snakes. His health soon began to suffer.

While waiting for the construction of the observatory to begin, Fallows used his own telescope to measure the exact positions of almost 300 southern stars from his temporary home in the gardens of a Cape Town house. In 1826, Fallows's professional-quality astronomical instruments finally arrived from England, along with his delayed assistant, Captain Ronald. The following year, observatory construction finally ended, 5 years after Fallows's arrival! Not until 1829 were the observing instruments finally installed at the observatory. As the observatory's director, Fallows quickly completed observations of 2,000 stars with a transit telescope, but an essential mural circle was found to have been damaged during unloading 2 years earlier. Again, no support came from the Admiralty Board back in England. By 1830, Fallows was so sick and weak that he needed to be carried in a blanket to work at the observatory. His last letter was received on 30 June 1831; he died the following month.

Fallows assisted in the funding and construction of the first Anglican chapel in South Africa.

Stuart Atkinson

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Fārābī: Abū Naṣr Muḥammad ibn Muḥammad ibn Tarkhān al-Fārābī

Born **Fārāb, (Turkmenistan), *circa* 870**
Died **Damascus, (Syria), 950**

Fārābī is mainly known as a philosopher, and his writings on the classification of the sciences, including astronomy and astrology, were influential both in the Islamic world and in Europe. Not much is known about Fārābī's early years. He studied logic with the Nestorian Christian Yuḥannā ibn Ḥaylān (died: *circa* 932) in Marw and then in Baghdad. In Baghdad, Fārābī studied Arabic and was therefore able to participate in the philosophical salons of Baghdad and to make use of Arabic philosophical and scientific works. He then went to Constantinople with his teacher during the reign of the ʿAbbāsid caliph al-Muktafī (902–908) or early during the reign of Caliph al-Muqtadir (908–932). He returned to Baghdad between 910 and 920, spending two decades there writing and teaching philosophy and allied sciences. In 942, Fārābī left Baghdad, probably to escape its instability, going first to Damascus and then to Egypt. He later returned to Damascus to join the court of the Ḥamdānid Prince Sayf al-Dawla but died a year later.

Fārābī is known primarily for his contributions to Islamic philosophy; he was known as "The Second Teacher" (*al-muʿallim al-thānī*), the First Teacher being **Aristotle**. His works include commentaries on Aristotle and **Plato**; introductory philosophical works; treatises on logic, metaphysics, political philosophy; and other philosophical disciplines; a treatise on the classification of knowledge, and works in the mathematical sciences, which include astronomy and music.

In *The Enumeration of the Sciences* (*Iḥṣāʾ al-ʿulūm*), Fārābī discusses the place of astronomy within the classification of knowledge, its subject matter, its demarcation from astrology, and its relationship with mathematics. He there classifies knowledge broadly into the major divisions of the linguistic sciences, logic, mathematics, physics, metaphysics, the civic sciences of ethics and political philosophy, law, and theology. Mathematics consists of seven branches: arithmetic, geometry, optics, astronomy, music, statics (*i. e.*, "the science of weights"), and technology. Astronomy, or the "science of the stars" (*ʿilm al-nujūm*), consists of two parts. The first is astrology (*ʿilm aḥkām al-nujūm*), which studies the signs of planets with regard to their relationship with future events, and sometimes also present and past events. The second part of astronomy is "mathematical astronomy" (*ʿilm al-nujūm al-taʿlīmī*), which, unlike astrology, is considered one of the mathematical sciences.

Mathematical astronomy investigates celestial bodies and the Earth with regard to their shapes, sizes, and distances; it investigates their motions, the components of these motions, the calculation of positions of planets as a result of these motions at any specific time, and the observable effects of motions, for example eclipses and planetary risings and settings. Furthermore, it investigates the inhabitable areas of the Earth, its climatic regions, and timekeeping, *i. e.*, seasonal hours. The determination that the Earth is entirely at rest at the center of the Universe and that motions of celestial bodies are spherical is made by mathematical astronomy.

Fārābī's grounds for rejecting astrology are clear in two surviving works: *On the Utility of the Sciences and the Crafts* (*Risāla fī faḍīlat al-ʿulūm wa-ʾl-ṣināʿāt*) and *On the Aspects in which Belief in Astrology Is Valid* (*Maqāla fī al-jihāt allatī taṣiḥḥu ʿalayhā al-qawl bi-aḥkām al-nujūm*). Fārābī acknowledges that celestial bodies have an effect on terrestrial bodies, but he believes this effect to be mediated through the light radiated by the celestial bodies. There is also a chain of causes from a particular position of a planet to its eventual effect upon a particular terrestrial body. Therefore, one is not dealing with a direct and necessary cause-and-effect relationship between planetary position and an immediate terrestrial effect, but rather with the relationship between a cause and its possible far-removed and remote effect. Any astrological prediction must take into account natural and voluntary obstacles that may prevent the occurrence of the eventual effect. Fārābī concludes that astrology is just conjecture, supposition, smooth talk, and deception.

Fārābī's philosophical cosmology was shaped by astronomy. He discusses the doctrine of the ten intellects in his *On the Opinions of the Inhabitants of the Virtuous City* (*Kitāb arāʾ ahl al-madīna al-fāḍila*). The First Intellect necessarily emanates from the First Being, namely God. Like the First Being, the First Intellect is immaterial. As it contemplates the First Being, the First Intellect necessarily brings a third being, namely the Second Intellect into existence. As it contemplates itself, the First Intellect necessarily brings the celestial heaven into existence. The Second Intellect also contemplates the First Being, which necessarily brings the Third Intellect into existence. The Second Intellect's contemplation of itself brings the sphere of fixed stars into existence. Similarly, the contemplation of the Third Intellect brings the Fourth Intellect and the sphere of Saturn into existence, the contemplation of the Fourth Intellect being brings the Fifth Intellect and the sphere of Jupiter into existence, and so on through the Tenth Intellect and the spheres of Mars, the Sun, Venus, Mercury, and the Moon. Thus Fārābī combines **Ptolemy**'s planetary spheres with Neoplatonic emanationism and necessity into a philosophical cosmology that would become the fundamental tenet of all subsequent Islamic Hellenistic philosophers (*falāsifa*). In their view, the celestial heavens were the realm of celestial intellects, souls, spheres, and planets.

Fārābī's *Commentary on Ptolemy's Almagest* (*Sharḥ al-Majisṭī*) is his only strictly astronomical work. The text has not yet been edited, but a Russian translation has been published, based on **Ibn Sīnā**'s shortened recension preserved in a British Library manuscript.

Alnoor Dhanani

Alternate name

Alfarabius

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Farghānī: Abū al-ˁAbbās Aḥmad ibn Muḥammad ibn Kathīr al-Farghānī

Flourished **Central Asia and Baghdad, (Iraq), 9th century**

Farghānī's main claim to fame rests upon his widely circulated compendium of **Ptolemy**'s *Almagest*, as well as on his writings on observational instruments. His name has also been associated with the Nilometer at al-Fusṭāṭ (near modern Cairo), as well as with the construction of an irrigation canal to supply the new city of al-Jaˁfariyya in Iraq built by Caliph al-Mutawakkil (reigned: 847–861). Not many biographical details are known. From his name, it appears that Farghānī was born in the vicinity of Farghāna in Transoxiana, probably about the beginning of the 9th century. He appears to have spent much of his career associated with the ˁAbbāsid court in Baghdad.

Farghānī's compendium (*jawāmiˁ*) of the *Almagest* was composed after the death of **Ma'mūn** in 833 but before 857. It was quite popular in Arabic, as testified in part by the surviving manuscript copies. It was also the subject of two commentaries, the first by **Abū ˁUbayd ˁAbd al-Waḥīd ibn Muḥammad al-Jūzjānī**, a student of **Ibn Sīnā**, and the other by **Abū al-Ṣaqr ˁAbd al-ˁAzīz ibn ˁUthmān al-Qabīṣī**. We know that **Bīrūnī** wrote an extensive discussion of this work entitled *Tahdhīb fuṣūl al-Farghānī*, but it is no longer extant.

Farghānī's compendium was, perhaps, even more influential in its Latin translations. The first of these was by **John of Seville** about 1135. Printed Latin versions based on this translation were published in Ferara (1493), Nuremberg (1537), and Paris (1546). The translation of **Gerard of Cremona** (made some time before 1175) was not printed until the 20th century, but it circulated in manuscript form throughout Europe. A Hebrew translation (before 1385?) of the Arabic text was prepared by Jacob Anatoli. This Hebrew version, together with the Latin version of John of Seville, was used by **Jacob Christmann** to prepare a new Latin translation, published in Frankfurt (1590). The Arabic text, together with a new Latin translation and notes (which cover only the first nine chapters), was published posthumously by Jacob Golius (Amsterdam, 1669).

Farghānī's treatise on the astrolabe survives in Arabic. (It appears not to have been translated into Latin.) It is a competent discussion of the mathematical principles of astrolabe construction directed toward serious scholars at an “intermediate” level, according to a statement in the introduction. This treatise also seems to have been somewhat influential, since a “supplement” (*Tatmīm ˁamal al-asṭurlāb*) was composed by Aḥmad ibn Muḥammad al-Azharī al-Khāniqī (flourished: 1350). An anonymous summary (*Tajrīd*) is also extant. Farghānī is also credited with a discussion of the construction of hour lines on horizontal sundials (*ˁAmal al-rukhāmāt*), but it seems not to be extant.

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Fārisī: Muḥammad ibn Abī Bakr al-Fārisī

Died ***circa* 1278/1279**

Fārisī was a scholar of wide learning and the author of some nine works on medicine, music, magic, and astronomy, which give us substantial information on both religious and mathematical astronomy. Little is known of Fārisī's life. His father appears to have emigrated from Persia, hence the name Fārisī. He was born in Aden and worked there at the Rasulid court of Sultan al-Muẓaffar Yūsuf (1249?–1295), the father of **Ashraf**. He probably died in 1278/1279. There is some confusion in the Arabic historical and the modern biobibliographical sources concerning him, possibly due to the subsuming of two different persons under one and the same name.

The confusion concerning the biographical dates of Fārisī is also reflected by the treatises attributed to him. Here only the astronomical treatises that we can most probably ascribe to Fārisī will be mentioned. The *Tuḥfat al-rāghib wa-turfat al-ṭālib fī taysīr al-nayyirayn wa-ḥarakāt al-kawākib* is a treatise on folk astronomy in 12 chapters, preserved in Milan and Berlin, which deals with chronology and calendars, the zodiacal signs and the lunar mansions, the determination of the position of the Moon and the Sun, timekeeping, the determination of the prayer times, reckoning twilight by the lunar mansions, finding the ascendant, lunar crescent visibility, and the *qibla*, *i. e.*, the sacred direction of Islam towards Mecca. The latter is needed for religious obligations such as the five daily prayers of Islam. This treatise provides particularly interesting and important information for the history of Islamic astronomy and its connection with the religion of Islam. Fārisī mentions the definitions of the five daily prayers, using a simple shadow scheme and a list of the values for the midday shadows at Aden for timekeeping by day, and using the lunar mansions as a star clock for timekeeping by night and for the determination around the morning twilight. The *Tuḥfa* contains three schemes; these organize the known inhabited world around the Kaaba, the focus of Muslim worship in Mecca, to determine the *qibla* by means of the winds and the risings and settings of the fixed stars and the Sun.

Fārisī also wrote an astronomical handbook with tables in the mathematical tradition of Islamic astronomy, known as *al-Zīj al-mumtaḥan al-muẓaffarī* (probably also known as *al-Zīj al-mumtaḥan al-khazā'inī*). It is dedicated to Fārisī's patron, al-Muẓaffar Yūsuf and written for the sultan's treasury (*al-khazā'in*). In the introduction to *al-Zīj al-mumtaḥan al-ʿarabī*, a recension of Farisī's *Zīj* preserved in Cambridge, the anonymous author characterizes Farisī's *Zīj* as the most elegant work that has been prepared on astronomy according to the longitude of Yemen. Fārisī bases his *Zīj* mainly on the observations of al-Fahhād (*circa* 1150) because, as he says in the introduction, the accuracy of the calculations and the demonstrations on which they are founded are superior to any that had done before, and because, more than any other *zīj*, it was compiled closer in time to the observations on which it was based. The 40 chapters and the extensive tables of Fārisī's text contain the standard information of a medieval *zīj*, such as calendars and chronology, planetary and spherical astronomy, timekeeping, and trigonometric procedures. Fārisī probably computed the spherical astronomical tables as well as the mean motions of the planets and the equations of their apogees, starting on 10 January 1262, using 63° 30′ for the geographical longitude and 14° 30′ for the geographical latitude, corresponding to Yemen or possibly Aden. In contrast to his folk astronomical treatise, he uses in his *Zīj* geometrical procedures for the determination of the *qibla*. The tables of Fārisī's handbook were widely employed in Yemen for several centuries and were adapted by later Yemeni astronomers. Various compilers of agricultural almanacs have copied from this *zīj* the coordinates for the asterisms of the lunar mansions and the *anwā'* (star groupings used for weather prognostication), and the times for their risings and settings throughout the year. Fārisī makes critical annotations to 28 other *zīj*es, including those of **Kūshyār ibn Labbān, Ibn Yūnus**, **Yaḥyā ibn Abī Manṣūr, Battānī**, and **Abū Maʿshar**. Most of the treatises mentioned by Fārisī are no longer extant, and *al-Zīj al-mumtaḥan al-muẓaffarī* is the only source providing us material about them. This *zīj* is a particularly rich source for al-Fahhād, for it names six *zīj*es by this author, none of which are extant. One of these is based on observations made in 1176 and mentions an observation of a conjunction of Saturn and Jupiter on 10 December 1166.

Also compiled for the Sultan's treasury was Fārisī's *Nihāyat al-idrāk fī asrār ʿulūm al-aflāk*, a treatise on astrology in three sections that is preserved, among other places, in Cairo. The first two sections of the *Nihāya* contain information on the *ikhtiyarāt* (elections), the third section on the 12 astrological houses. Dates of completion are garbled; a possible date is 1262. In the introduction, three other works by Fārisī, that he wrote for his patron's treasury, are mentioned. One of them deals with sundials (*al-Risāla al-ẓilliyya* or *Risālat al-ẓill al-mabsūṭ*); another contains an eclipse computer (*al-Risāla al-muẓaffariyya fī al-ʿamal (or bi-'l-āla?) al-musammā bi-'l-ṣafīḥa al-jawzahariyya*); the third treatise mentioned may be Fārisī's *Zīj*. The first two works are no longer extant. The *Nihāya* was known outside Yemen.

Also known outside Yemen was Fārisī's *Kitāb Maʿārij al-fikr al-wahīj fī ḥall mushkilāt al-zīj.* It is also preserved, among other places, in Cairo and deals with a discussion of the standard topics of planetary and spherical astronomy that one will find in the introductions of *zīj*es.

For the sake of completeness, mention is made of an Arabic translation made by Fārisī of an astrological treatise written by Jāmāsp, a contemporary of Zarathustra; it is preserved in a single copy in Milan.

Fārisī is significant for a number of reasons. By writing treatises both in the popular tradition of astronomy (his *Tuḥfa*) and in the mathematical tradition (his *Zīj* as well as his *Maʿārij* and his *Nihāya*), he brings together in a single person two different traditions that are often seen in opposition: "religious astronomy," represented in folk astronomical treatises with their discussions of prayer times, the *qibla* and the lunar crescent visibility, and mathematical traditions of astronomy and astrology inherited from the ancients. Fārisī is also significant because of the substantial information he records of both traditions. In his *Zīj*, he mentions numerous scholars and their treatises, most of them not preserved, as we have seen in the case of al-Fahhād and his observations. Besides Byzantine texts, this is the most important source on this astronomer. In his *Tuḥfa*, Fārisī explains the astronomical alignment of the Kaaba in Mecca and elucidates the principle behind the *qibla* schemes, schemes that are part of a tradition representing the Kaaba as the center of the world.

Petra G. Schmidl

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Fath, Edward Arthur

Born **Rheinbischofsheim, (Baden-Württemberg), Germany, 23 August 1880**
Died **Tacoma, Washington, USA, 26 January 1959**

American observational astronomer Edwin Fath made four significant discoveries: that spiral nebulae have spectra like star clusters; as an exception to that observation, that a few spiral nebulae have broad emission lines; that the spectrum of zodiacal light is that of reflected sunlight; and that there is a class of pulsating variables with more than one pulsation period per star. He was the son of the Reverend and Mrs. Jacob Fath and married Rosina Kiehlbauch in 1909 (died: 22 November 1939); his second marriage was to Mrs. Olive M. Hawver in 1942 (died: 11 September 1957). The Faths had two daughters, Catherine Fath (Sherry) and Miriam Fath (Boom).

Fath began his education at Wilton College in Iowa and graduated from Carleton College in 1902. He completed 1 year of graduate study at the University of Illinois under **Joel Stebbins** and, in 1906, he entered the graduate program at the University of California, Berkeley, where Fath earned the Ph.D. in 1909 after studies at the Lick Observatory.

After graduation from Carleton College, Fath taught science and mathematics at Wilton College until 1905 and then became an instructor in astronomy at the University of Illinois, 1905/1906. From 1909 to 1912 he was an assistant astronomer at the Mount Wilson Observatory, where he continued the spectrographic studies of spiral nebulae and star clusters on which he had based his Lick Observatory dissertation. Fath became director of the Smith Observatory of Beloit College in Beloit, Wisconsin, in 1912. From 1914 to 1920 he was president of Redfield College in Redfield, South Dakota. Fath joined the faculty of his *alma mater*, Carleton College, in 1920, and in 1926 he became director of Goodsell Observatory and chairman of the Department of Astronomy, from which he retired in 1950. On his retirement, Fath presented the college with a small planetarium, which is still in use. He was also either an editor or an associate editor of *Popular Astronomy* from 1920 to 1938. Fath was a fellow or member of the American Astronomical Society, the Societé Astronomique de France, the Royal Astronomical Society, the American Association for the Advancement of Science, and Sigma Xi.

Fath's most significant contribution to astronomy derives from his dissertation, carried out with **William Campbell**, director of the Lick Observatory. The dissertation was a significant research effort. In 1899, **Julius Scheiner** at the Potsdam Observatory had found the spectrum of the great spiral nebula M 31 in Andromeda to contain dark absorption lines reminiscent of the solar spectrum. Using a specially designed fast spectrograph and long exposures with the Crossley reflector, Fath examined the spectra of a number of spiral nebulae and checked these against the spectra of some globular clusters (which clearly consisted of stars). He found that the spectra of the spiral nebulae were stellar in nature. This was a major contribution toward solving the problem of the nature of the spirals. Fath's spectra provided evidence that these objects were congeries of stars, "island universes." However, as Fath had no measure of the distances of any of the spirals, it was not proof. Fath continued his work on nebulae at Mount Wilson, with a more powerful reflecting telescope but a less suitable spectrograph. Here he was able to extend his earlier work until his post came to an end in 1912. Nevertheless, Fath's dissertation research revealed the true nature of the spiral nebulae. He does not himself seem to have made as much of this discovery as one might expect, but the situation was somewhat confused by his spiral sample having included the first couple of examples of the class of galaxies now named after **Carl Seyfert**, which have very bright nuclei with spectra dominated by broad emission lines, produced by hot, diffuse gas, not by stars. Fath also used the nebular spectrograph to obtain the first spectrogram of zodiacal light that showed absorption features identical to those in reflected solar light, to within the accuracy of the determination.

After Fath's arrival at Carleton, he became interested in the study of variable stars, and he dedicated himself in particular to δ Scuti, a pulsating variable that he studied with a photoelectric photometer at Lick Observatory during the summers of 1935 and 1938. δ Scuti is the prototype of a group of stars that vary with multiple periods, and Fath discovered its peculiarity.

Fath's work on *Popular Astronomy* preserved the semi-technical tone of the journal, which became the home of historical articles, surveys of recent research, and a chronicle of publications and professional activities, as well as an outlet for amateur astronomers' work. Under Fath's editorship, *Popular Astronomy* remained preeminent until the founding of *Sky & Telescope* in the 1940s, and a shorter but better-illustrated magazine.

Fath also published two books. His elementary textbook, *Elements of Astronomy*, published in 1926, was very popular and went through five editions into the 1950s. This work and the contemporary textbook by **John Duncan** were the introductory books of choice on college campuses until the later editions of Robert Baker's textbook. A more popular book, *Through the Telescope* (1936), told the story of modern astronomical research through the novel perspective of a visitor to the great American observatories. It sold well and may still be found in many public libraries.

Fath's great work came early. His researches at Lick, pursued at Mount Wilson, established the nature of the spiral nebulae as vast assemblies of stars; final proof had to await the definitive measurement of distances by **Edwin Hubble**. Deprived of the opportunity to use a major research instrument, Fath then became an influential and beloved educator, an editor of the most popular journal in the field, and discoverer a new class of variable stars that he made particularly his own.

Records pertaining to and letters by Fath appear in the archives of Carleton College and also in the archives of the Lick and Mount Wilson observatories.

Rudi Paul Lindner

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Fauth, Philipp Johann Heinrich

Born **Bad Dürkheim, (Rheinland-Pfalz, Germany), 19 March 1868**
Died **Gruenwald, Bavaria, Germany, 4 January 1941**

Philipp Fauth was the last of the great lunar cartographers to rely principally on visual observations. The oldest of three children born into a long-established family of pottery-makers, his interest in astronomy was kindled at about the age of seven when he was awakened by his father and carried outside to see comet Coggia (C/1874 Q1) gleaming in the predawn sky. Like **William Herschel**, Fauth was a musical prodigy, having taken up the violin at the tender age of five. While music would remain a lifelong passion, Fauth chose to become a schoolteacher.

In 1890, Fauth established a private observatory atop a grass-covered knoll on the outskirts of Kaiserslautern. His observatory was equipped with a refractor of 162-mm aperture. In 1893 and again in 1895 he issued impressive monographs; the latter contained topographic charts of 25 selected regions of the Moon, masterfully executed in the hachure technique employed by all of the leading German selenographers after **Wilhelm Lohrmann**, and an announcement that the author intended to eventually produce a new lunar map on a scale of 1:1,000,000 that would be based on outlines derived from photographs, with finer details inserted from visual observations. Articles by Fauth began to appear frequently in the leading German astronomical journals, *Astronomische Nachrichten* and *Sirius*.

The depth of understanding of the nature of lunar topography demonstrated by Fauth was superior to that possessed by the majority of his contemporaries. The morphology revealed by his methodical measurements of the depth-to-diameter ratios of hundreds of lunar craters and the slopes of their exterior and interior walls led him to reject the prevailing volcanic theories of the origin of lunar craters.

Unfortunately, in 1906 Fauth advanced the idiosyncratic notion that "the Moon is covered with a thick rind of ice surrounding an ocean of liquid water, which in turn covered a rocky core." His energies were increasingly diverted into a collaboration that was destined to have tragic consequences. Since 1894 he had been corresponding with a fellow amateur astronomer living in Vienna, **Hanns Hörbiger**, a former blacksmith's apprentice who had taken up engineering and become a successful designer of valves, pumps, and mining equipment. Like Fauth, Hörbiger had long harbored notions of an icy Moon – the first of many astronomical theories that came to him in flashes of intuition, visions, and vivid dreams, as if they were the products of some form of mystical illumination. With the unwavering conviction of the delusional psychotic, Hörbiger embarked on a flurry of manic activity so all-consuming that it had to be interrupted by a rest cure taken on the advice of a physician. Observatories throughout central Europe were bombarded with letters and telegrams, often followed up by what must surely have been unwelcome personal visits.

Fauth was quickly converted, however, and soon became Hörbiger's greatest disciple. For the next decade Fauth's lunar mapping ground to a virtual standstill as he and Hörbiger labored to produce a *magnum opus*. The strange product of their collaboration was *Hörbigers Glazial-Kosmogonie* (Hörbiger's glacial cosmogony), written mostly by Fauth but containing lengthy sections contributed by Hörbiger. It is a turgid, 790-page tome printed in double columns, replete with no fewer than 212 illustrations. Published in 1913 on the eve of World War I, Fauth called the book "my second life's work."

Hörbiger and Fauth attributed the swift and decisive rejection of their theories by "reactionary" astronomers to simple jealousy. Wanton alienation of the astronomical community ensued, with irreparable damage to Fauth's reputation. To many, his name became anathema. Others who grudgingly admired his talents as an observer and cartographer regarded him as a virtual "idiot savant."

Hörbiger died in 1931, embittered by the failure of the scientific community to embrace glacial cosmogony. Almost as if a spell had been broken, within a year of Hörbiger's death Fauth issued a 16-section regional lunar atlas, the labor of an extended period of convalescence from a severe illness that had interrupted his observations. These magnificent charts were depictions on a huge scale of 1:200,000 of Copernicus, Eratosthenes, Ptolemaeus and other notable features, carefully corrected for foreshortening, and some rendered in carefully estimated contour lines rather than the hachures of his earlier work. He also announced that pencil drafts of the 22 sheets of his long-awaited *Grosse Mondkarte* (Large Moon Map) were all but complete. Its scale of 1:1,000,000 would correspond to a diameter of 3.5 m (11.5 ft.). Since Fauth incorporated almost 5,000 reference points – some based on measurements made with a visual micrometer by **Julius Franz** at the Königsberg and Breslau observatories, and others derived by **Samuel Saunder** from photographic negatives obtained at the Paris and Yerkes observatories – the atlas would surpass any previous achievement in lunar cartography not only in uniform richness of detail but in positional accuracy as well.

In 1936, Fauth's most valuable work appeared. Entitled *Unser Mond* (Our Moon), it was described by the late **Joseph Ashbrook** as "the best of all observing guidebooks to the Moon's surface," but sadly it has remained virtually unknown to an English-speaking readership. Subtitled *Neues Handbuch für Forscher nach Erfahrungen aus 52 Jahre Beobachtung* (New handbook for researchers according to experiences from 52 years observation), it contains topographical descriptions of every major lunar formation, complete with summaries of their observational histories. It was meant to serve as the companion text to the still unfinished 1:1,000,000 map. Instead, it appeared in conjunction with a map of one-fourth that scale in 16 sections (the *Obersichtkarte des Mondes* or Overview Map of the Moon), which was intended to serve as a guide to nomenclature. While the glacial cosmogony was virtually banished to one of the appendices, age had not completely mellowed Fauth.

The rest of Fauth's career can be briefly summarized. In 1937 he issued a large collection of drawings of formations located near the lunar limb, observed under conditions of especially favorable libration. Progress on the *Grosse Mondkarte*, however, remained painfully slow, since every night at the telescope revealed new features that he felt compelled to add. When Fauth died, he was satisfied that only five of the 22 sheets of the 1:1,000,000 map were complete. He was in the midst of preparations to move his observatory from Grünwald to a more favorable site at Rauhe Alb in Swabia and had just begun to commit his thoughts to paper for a final work, to be entitled *Selenographie, Ein Weg zur Aufhellung von Welträtseln: Mein Bekenntnis und Vermächtnis an Künstige Mondbeobachter* (Selenography, a path to shed light on the riddles of the Universe: My testament and bequest to future lunar observers).

Fauth's 1:1,000,000 map was completed by his son Hermann, and finally printed in 1964. Unfortunately, the son did not draw with the skill and assurance of the father, so the final and long-awaited result was a disappointment as well as an anachronism. By then, the United States Air Force Aeronautical Chart and Information Center had undertaken the preparation of Lunar Astronautical Charts on the same 1:1,000,000 scale of the *Grosse Mondkarte*. These beautiful airbrushed maps, the product of inserting minute details glimpsed visually through the Lowell Observatory's 24-in. refractor onto outlines of coarser features derived from the finest photographs obtained at several observatories, represented 8 years of work by a 22-member staff that included a dozen professional illustrators and cartographers. Recalling this fact makes Fauth's solitary achievement all the more remarkable.

Thomas A. Dobbins

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Faye, Hervé

Born **Saint Benoît-du-Sault, Orne, France, 1 October 1814**
Died **Paris, France, 4 July 1902**

Hervé Faye, whose researches were largely theoretical in character, enunciated a model of the Sun and discussed the effects of solar radiation pressure on the motions of comets, arguing that this repulsive force was responsible for the tail phenomena. Faye was the son of a civil engineer, whose interest in astronomy developed a year or two after he entered the École Polytechnique in 1832. Four years later, he acquired a position at the Observatoire de Paris and worked under director **Dominique Arago**. Faye calculated the orbit of comet 4P/1843 W1, which he discovered telescopically on 22 November and for which he was awarded the Lalande Prize of the Académie des sciences. He also calculated the orbits of two other periodic comets. Thereafter, his career progressed in several directions.

From 1848 to 1854, Faye lectured on geodesy at the École Polytechnique and was appointed a full professor in 1873. He also held the professorship of astronomy at Nancy, and as rector of the academy there, served as general inspector of its secondary schools. Faye was president of the Bureau des longitudes for more than two decades. He was a delegate to the Astrographic Congress (1887).

In 1884, Faye published *Sur l'origine des mondes* (On the origin of worlds), a historical account of ancient and modern cosmogonies. Therein, he modified the nebular hypothesis of **Pierre de Laplace**, although few of his contemporaries accepted Faye's notions. He undertook various geodetic projects at home and abroad and came close to proposing the modern concept of isostasy. Faye understood the relationship between comets and meteoroids, advocated photography in celestial observations, appreciated that refraction is a major source of error, and designed a zenith telescope.

Faye's gaseous model of the Sun, in which he conceived of sunspots as openings displaying internal cyclonic motions, was widely adopted. Likewise, he studied terrestrial cyclones in this context. Finally, he played a leading role in the controversy surrounding the purported existence of the planet Vulcan. For his services to the French government, Faye was awarded the Grand Cross of the *Légion d'honneur*.

Richard Baum

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Fazārī: Muḥammad ibn Ibrāhīm al-Fazārī

Born **possibly (Iraq), 8th century**
Died **possibly Baghdad, (Iraq), early 9th century**

Fazārī played a pivotal role in the initial development of the Arabic astronomical tradition from Indian, Sasanian, and Greek sources, but almost nothing of his own works remains with us. Not even his identity is entirely certain: there was some ambiguity among medieval biographers as to whether "Ibrāhīm ibn Ḥabīb al-Fazārī" and "Muḥammad ibn Ibrāhīm ibn Ḥabīb al-Fazārī" were two different people, namely father and son. It is now assumed, however, that the various references to the astronomer Fazārī mean the same individual.

This individual was apparently a descendant of an old family in Kūfa (near Najaf in modern Iraq) and worked on astronomy and astrology – particularly the composition of astronomical handbooks with tables for computing celestial positions (*zīj*es) – at the court of al-Manṣūr (reigned: 754–775) and later ʿAbbāsid caliphs. He helped supervise the casting of the horoscope that selected the auspicious date for the founding of Baghdad in 762. In the early 770s, at the caliph's request, he collaborated in the translation of a Sanskrit astronomical text brought to Baghdad by an Indian astronomer. Fazārī based his *Zīj al-Sindhind al-kabīr* (Great astronomical tables of the *Sindhind*; from Sanskrit siddhānta, "system" or "treatise") on that work. Probably a decade or so later, he wrote another *zīj* entitled *Zīj ʿalā sinī al-ʿArab* (Astronomical tables according to years of the Arabs). Fazārī also composed – apparently in imitation of the style of Sanskrit technical treatises in metrical verse – a long poem on astronomy and/or astrology, *Qaṣīda fī ʿilm* (or *hay'at*) *al-nujūm* (Poem on the science [or configuration] of the stars). Some scattered remarks on these works, with occasional citations from them, are found in the works of later authors.

Also ascribed to Fazārī, but known only from their titles, are *Kitāb al-Miqyās li-'l-zawāl* (Book on the measurement of noon), *Kitāb al-ʿAmal bi-'l-asṭurlāb wa-huwa dhāt al-ḥalaq* (Book on the use of the armillary sphere), and *Kitāb al-ʿAmal bi-'l-asṭurlāb al-musaṭṭaḥ* (Book on the use of the astrolabe). Fazārī was said to have been the first Muslim to construct a plane astrolabe; indeed, according to several biographers, he was a pioneer and positively unrivaled in his mastery of the astral sciences. The 11th-century astronomer **Bīrūnī** (from whom comes most of our knowledge of details of Fazārī's astronomy) is somewhat more critical, especially about probable mistakes of Fazārī and his colleague **Yaʿqūb ibn Ṭāriq** in interpreting the terms or techniques of the Sanskrit astronomical work they translated.

Although, as noted above, Fazārī based his first *zīj* primarily upon this Sanskrit text (probably entitled *Mahāsiddhānta* or Great Siddhānta), he seems to have added to it a good deal of material from other sources. The *Mahāsiddhānta* apparently belonged to the Indian astronomical tradition associated with the 7th-century *Brāhmasphuṭasiddhānta* of **Brahmagupta**, but the features ascribed in the comments of later authors to the *Zīj al-Sindhind al-kabīr* are an eclectic (and sometimes flatly contradictory) mix, including parameters and procedures derived not only from rival Indian schools, but also from the Sasanian Persian astronomical tradition, with a little Ptolemaic influence as well.

Fazārī is credited with the innovation of converting the Indian planetary longitude computus involving billions of revolutions (suffering, as **Hāshimī** remarked, from "the length of its operations in multiplication and division and the tedious nature of the computations") into ones using sexagesimal values of mean motions. (In fact, Indian astronomers too had tabulated and used sexagesimal mean motions.) His second *zīj*, according to its title and a surviving table copied from it into later works, was designed to enable the user to find the desired positions for dates in the Arabic calendar. Even these fragmentary references suffice to show that Fazārī's contributions had a significant impact on nascent Arabic astronomy, although his work as a whole did not withstand competition from later (and presumably better-organized) treatises.

Kim Plofker

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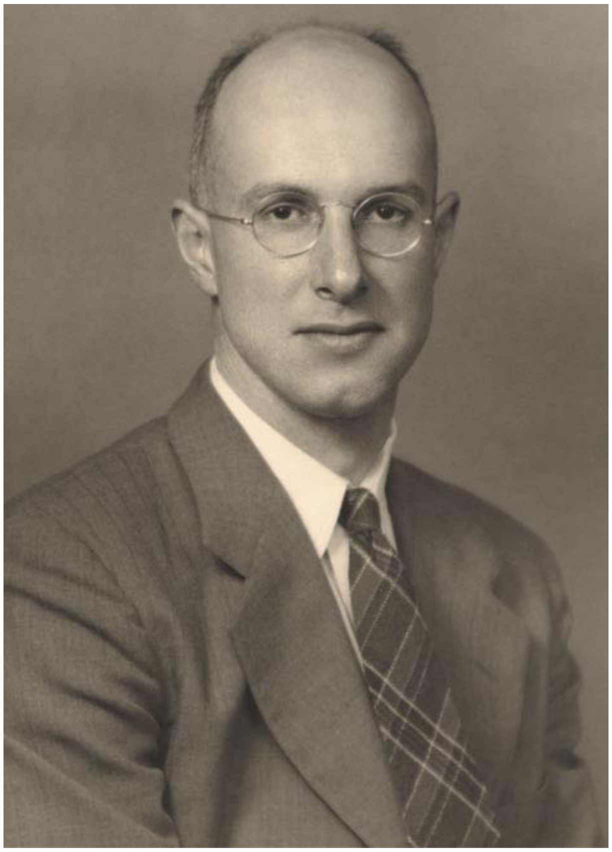
Pingree, David (1970). "The Fragments of the Works of al-Fazārī." *Journal of Near Eastern Studies* 29: 103–123. (The extant information about

Fazārī's writings are collected herein; few additional details have come to light since.)

Sezgin, Fuat (1978). *Geschichte des arabischen Schrifttums*. Vol. 6, *Astronomie*, pp. 122–124. Leiden: E. J. Brill.

Federer, Charles Anthony Jr.

Born **Saint Louis, Missouri, USA, 1 January 1909**
Died **Mystic, Connecticut, USA, 28 September 1999**



Charles (Charlie) Federer, Jr., dramatically advanced the popularization of astronomy during the 20th century. Self-taught in astronomy, he obtained a BS degree in mathematics and physics from City College, New York, while working as a marine-insurance underwriter. From 1935 to 1941, as an original staff member of the American Museum–Hayden Planetarium, he was an assistant and a lecturer; from 1939 he was editor of its magazine, *The Sky*.

Together with his wife, Helen (*née* Spence), in 1941 Federer merged *The Sky* with *The Telescope* (published by Harvard College Observatory) to create *Sky & Telescope*. The result was a modern magazine, in contrast to the journal-format *Popular Astronomy*, which was the dominant United States astronomical publication at that time. (*Popular Astronomy* ceased publication in 1951).

The Federers' genius was that they established an editorial formula that simultaneously catered to amateur and professional astronomers, telescope makers, and educators – and they augmented the magazine with abundant graphics. They also established a very high standard for accuracy and fidelity. One legacy of their creation is that it sparked many people to become engaged professionally – especially at the beginning of the space age – and it caused legions to support astronomy. *Sky & Telescope* also provided a means for many entrepreneurs to connect with enthusiasts; small businesses related to astronomy blossomed after the magazine's establishment.

The Federers were also instrumental in founding what is now called the Astronomical League, today the largest organization of amateur astronomers in the world. The Federers separated in 1957 and were divorced in 1965. Helen Spence Federer was no longer associated with *Sky & Telescope* but remained actively engaged in astronomy through employment at the Harvard College Observatory.

Federer retired as *Sky & Telescope*'s editor-in-chief in 1974 and was honored in 1991 with the naming of minor planet (4726) Federer. He also edited the magazine *Weatherwise,* for amateur meteorologists, from its founding in 1948 through 1952.

Leif L. Robinson

Selected Reference

Robinson, Leif J. (1990). "Enterprise at Harvard College Observatory." *Journal for the History of Astronomy* 21: 89–103.

Feild, John

Flourished **England, 1556**

John Feild published *Ephemeris Anni 1557* – the first English astronomical tables based on Copernican theory. The preface, by **John Dee**, advocates heliocentricism.

Selected Reference

Johnson, Francis R. (1936). "The Influence of Thomas Digges on the Progress of Modern Astronomy in Sixteenth-Century England." *Osiris* 1: 390.

Fényi, Gyula

Born **Sopron, (Hungary), 8 January 1845**
Died **Kalocsa, Hungary, 21 December 1927**

Under Gyula Fényi's direction the Haynald Observatory became a leading heliophysical institute.

Fényi was the 11th child of his parents, Ignác Finck and Anna Mária Binder. At the age of 12 he became orphaned. After finishing studies in the secondary school (Sopron: 1864), Gyula became seriously ill, and while undergoing medical treatment he became acquainted with a Jesuit father. In 1864 he entered the Society of

Jesus. He studied in Nagyszombat and became a teacher of physics, mathematics, chemistry, and natural history in Kalocsa (1871). Early in his teaching practice he adopted the last name Fényi. In 1874–1878 he studied theology, mathematics, and physics in Innsbruck, Austria, and was ordained priest in 1877. Fényi became an assistant at Haynald Observatory in Kalocsa, and between 1885 and 1913, director of Haynald Observatory.

Fényi was a member of the Accademia Pontificia dei Nuovi Lincei (1902), foreign member of the Società degli Spettroscopisti Italiani (1909), and corresponding member of the Hungarian Academy of Sciences. He was honorary president of the Instituto Solar International Montevideo (1903).

Between 1885 and 1917 Fényi regularly observed solar prominences using a 7-in. refractor. (A Hilger spectroscope was available at Kalocsa, too.) Fényi's drawings constitute an extensive and accurate database of this phenomenon. He followed the changes in the shape of prominences and their speed of emergence, and also studied the relationship between the prominences and geomagnetic phenomena.

Fényi also studied sunspots and faculae. He concluded that solar atmospheric and surface activity is caused by permanent solar processes generated inside the Sun.

Fényi's research activity in the field of meteorology is also noteworthy. A crater on the Moon is named for him.

László Szabados

Alternate name

Finck, Julius

Selected Reference

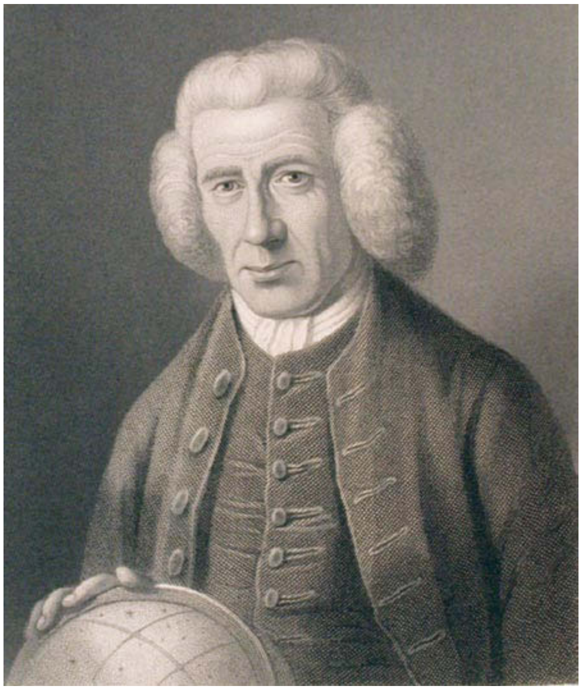
Anon. (1928). "Todesanzeige: Fényi." *Astronomische Nachrichten* 232: 303–304.

Ferguson, James

Born **near Keith, (Grampian), Scotland, 25 April 1710**
Died **London, England, 16 November 1776**

James Ferguson was an astronomical and philosophical lecturer, modelmaker, and clockmaker. Ferguson came from a large family that scratched a meager living off a few acres of rented land. Money was scarce and education a low priority. With a little help from a neighbor, James taught himself to read, and received instruction in writing from his father. Apart from 3 months at the grammar school in Keith, he had no formal education. The first half of his life was spent in Scotland, earning a living by drawing miniature portraits. He married Isabella Wilson on 31 May 1739, and had four children.

Although Ferguson is usually labeled an astronomer, his interests were many and included electricity, mechanics, horology, and chronology. He was never a practical astronomer; other than his extensive writings, his contributions to the subject were his lectures and the working models such as orreries and globes he constructed to explain celestial phenomena.



Ferguson's interest in astronomy developed in his youth as he watched the night sky while employed as a shepherd. Coupled with his ability to design and make models to replicate the celestial motions, this experience led him in 1743 to seek his fortune in London as an astronomer. His lectures on the subject to "Gentlemen and Ladies," enlivened by demonstrations, experiments, and working models, invariably made by himself, proved so popular that by the late 1740s he extended his circuit to include major English provincial towns and cities such as Bath, Liverpool, and Manchester. By then he was well known for his orreries, globes, and other devices, and was becoming an elder statesman in the world of science and technology. In 1761, George III awarded him the grant of a pension, and 2 years later the Royal Society elected him a fellow. By now his fame had spread to such an extent that in 1770 the self-taught shepherd–astronomer was elected to membership of the equally prestigious American Philosophical Society.

During his career in London, which continued for 33 years, Ferguson contributed numerous writings to the *Philosophical Transactions*, and periodicals like *The Gentleman's Magazine*, and published several books, including two major texts: *Astronomy Explained upon Sir Isaac Newton's Principles* (1756) and *Lectures on Select Subjects in Mechanics* (1760). All of these were very popular, due largely to the absence of mathematics and a clear, unpretentious style.

Richard Baum

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Fernel, Jean-François

Born **Montdidier, (Somme), France, *circa* 1497**
Died **Fontainebleau, (Essonne), France, 1558**

Although Jean-François Fernel had an early interest in and studied astronomy, writing several papers on the size and behavior of the Earth, he soon turned his back on astronomy to pursue his main interests – physiology and medicine.

Fernel was the son of a furrier and innkeeper. After schooling at Claremont, Fernel studied mathematics, astronomy, and philosophy at the College de Sainte Barbe, Paris. He received his MA at the age of 22, and completed his medical training at University of Paris, where he obtained his MD in 1530.

Often referred to as "The Father Of Pathology," Fernel was considered to be one of the greatest physicians of the Renaissance, and wrote a number of books that remained in use long after his death. In 1554 Fernel published *Medicina*, his most important work, a systematic survey of what was then known about human disease. Two years later Fernel became physician to the court of Henry II, and was given the position of "physician in chief" to the Dauphin. He died of fever.

Stuart Atkinson

Selected Reference

Forrester, John M. and John Henry (2005). *Jean Fernel's On the Hidden Causes of Things: Forms, Souls, and Occult Diseases in Renaissance Medicine*. Leiden: Brill.

Ferraro, Vincenzo Consolato Antonino

Born **London, England, 10 April 1902**
Died **probably London, England, 3 January 1974**

British mathematical physicist Vincenzo Ferraro was one of the pioneers in the study of ionized gases in the presence of a dynamically important magnetic field, now called magnetohydrodynamics [MHD]. He was educated at Imperial College, University of London, where he took his Ph.D. under the supervision of **Sydney Chapman**, then the chief professor of mathematics at Imperial College. They developed the Chapman–Ferraro theory of geomagnetic storms (1930). Chapman and Ferraro assumed that discrete plasma streams were emitted from solar flares. Assuming that such a stream behaves like a perfectly conducting fluid, they suggested that the stream pushes the geomagnetic field before it and is itself retarded, so that a temporary magnetospheric cavity is produced in the front of the stream. Later, the theory had to be modified when the solar wind was discovered. However, treating the stream as a fluid and not as a collection of independent particles was a new concept.

Ferraro remained at Imperial College as a demonstrator in mathematics from 1930 to 1933, and then became a lecturer at King's College, London. In 1937 he formulated his isorotation theorem: A nonuniformly rotating cosmic mass of plasma permeated by a magnetic field rapidly approaches a state in which the angular velocity is constant along a field line. This result turned out to be important in later studies of star formation in magnetized gases. In 1947 he was appointed professor of applied mathematics at the University College of the Southwest at Exeter. In 1952 Ferraro became professor of mathematics at Queen Mary College, University of London. He and his students made applications of what was by then known as magnetohydrodynamics to problems such as the oscillations of a magnetic star and the braking of the solar rotation by the solar wind.

Ferraro wrote two textbooks, *Electromagnetic Theory* (1954) and, with C. Plumpton, *Introduction to Magneto-Fluid Mechanics* (1961). He was active in Commission 10 (solar activity) of the International Astronomical Union and had strong interests in art, which he had hoped to take up again after his retirement, scheduled for September 1974, but death intervened.

Roy H. Garstang

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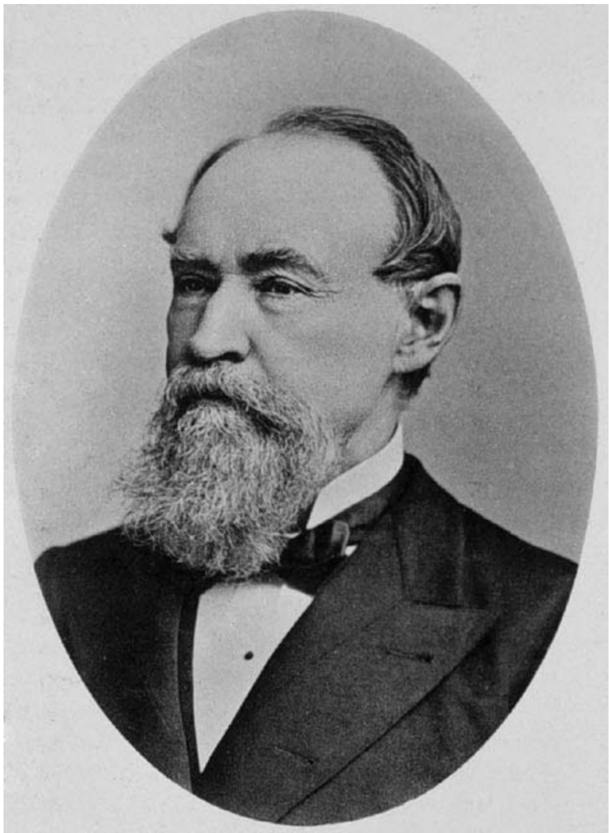
Ferrel, William

Born **Bedford (Fulton) County, Pennsylvania, USA, 29 January 1817**
Died **Maywood, Kansas, USA, 18 September 1891**



William Ferrel was a self-taught American meteorologist and geophysicist best known for his maxima and minima tide-predicting machine, for Ferrel's law, and as the father of geophysical fluid dynamics. He was the son of Benjamin Ferrel, a farmer and sawmill operator; his mother's maiden name was Miller. In 1829, the family relocated from Pennsylvania to a farm in Berkeley County, Virginia (today Martinsburg, West Virginia). William attended public schools and worked on the family farm. His curiosity about the scientific world around him made him a passionate reader on mathematics, surveying, and mathematical physics. With money saved from teaching, he attended Marshall College in Mercersburg, Pennsylvania, beginning in 1839, and later transferred to the new Bethany College, Bethany, Virginia. Following graduation from Bethany in 1844, Ferrel continued teaching, first at Liberty, Missouri (1844–1850), then at Allenville, Kentucky (1850–1854), and finally in Nashville, Tennessee, until 1857, where he opened his own school.

Ferrel taught himself mathematics, including algebra, geometry, and trigonometry. He pursued his mathematical studies according to the availability of books rather than by following the traditional route, and he learned land surveying from a professional who lived in the area. Ferrel's early years of educational deprivation, and his later years of intellectual isolation, left his mind open to original methods of thought. His interest in astronomy, which began in the early 1830s, prompted him to ponder mathematical complexities, such as the prediction of eclipses. The essays of **George Airy**, including his "Figure of the Earth" and "Tides and Waves," influenced Ferrel's study of the oceans and the atmosphere.

While in Liberty, Ferrel found for sale a copy of **Isaac Newton**'s *Principia*, which he studied in detail. Newton's explanation of tides particularly intrigued him, and following extensive study, Ferrel correctly concluded that the motion of the tides influenced the speed at which the Earth rotated. Ferrel also studied **Nathaniel Bowditch**'s translation of the classic work *Mécanique céleste* by **Pierre de Laplace**. He was further influenced by physicist **Jean Foucault**'s studies of the Earth's rotation using his pendulum and gyroscope, and by **Matthew Maury**'s publication *Physical Geography of the Sea* (1855).

Ferrel published his first paper in 1853 in **Benjamin Gould**'s *Astronomical Journal*, in which he correctly argued the accuracy of the equations Laplace used in his work on tides. This was followed in 1856 by the publication of his "Essay on the Winds and Currents of the Ocean" in the *Nashville Journal of Medicine and Surgery*. Ferrel's work on this topic culminated in 1858 with his conclusion, later dubbed Ferrel's law,

> … that if a body is moving in any direction, there is a force arising from the Earth's rotation, which always deflects it to the right in the northern hemisphere, and to the left in the southern.

This was an independent statement of what is now called the Coriolis effect. He later showed how this law could explain storms, wind patterns, and ocean currents.

Ferrel's advancements in science earned him a position in the US Navy's Nautical Almanac Office in Cambridge, Massachusetts. This appointment placed him in proximity to libraries, and in an intellectually stimulating environment among mathematicians and astronomers, such as **Benjamin Peirce**, Gould, **Asaph Hall**, and **Simon Newcomb**. When Pierce became superintendent of the United States Coast Survey in 1867, Ferrel followed him to Washington.

In 1876, about the same time that **William Thomson** (Lord Kelvin) developed a tide-predicting machine, Ferrel independently built a tide machine of a somewhat different, more compact and refined design, which predicted minimum and maximum tides. Ferrel's tide-predicting machine was put into service in 1883 and was unrivaled for the next 25 years. The chief of the Tidal Division of the Coast and Geodetic Survey stated that Ferrel's tide machine performed the labor of 40 (human) computers.

Ferrel's continuing interest in astronomy led him to use tidal data to calculate the mass of the Moon. The publication from 1877 to 1882 of his three-volume *Meteorological Researches* led to Ferrel's employment from 1882 to 1886 as a meteorologist with the United States Army Signal Service, which was responsible for the nation's weather service prior to the creation of the Weather Bureau in 1891. American meteorologist **Cleveland Abbe** credited Ferrel's 1859/1860 memoir in the *Mathematical Monthly* on the mechanics of the atmosphere as being "… to meteorology what the *Principia* was to astronomy …."

Ferrel retired to Kansas in 1887 to live with his family, and died there. He never married.

Patricia S. Whitesell

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Fleming, James Rodger (1990). *Meteorology in America, 1800–1870*. Baltimore: Johns Hopkins University Press.

Fesenkov, Vasilii Grigorevich

Born **Novocherkassk, Russia, 13 January 1889**
Died **Moscow, (Russia), 12 March 1972**

After the Bolshevik Revolution, Vasilii Fesenkov, a astrophysicist of the older generation, was the leading planetologist and scholar in meteoritics of the pre-spaceflight era, one of only a few academicians (Soviet Academy of Sciences) in the field of astronomy (from 1935), and an outstanding and enthusiastic promoter of Soviet astronomy.

Fesenkov was a 1911 graduate of Kharkov University. (After the disintegration of the USSR, it came into the possession of the Republic of the Ukraine.) One of his teachers was **Gustav Struve**. In 1912–1914, he received internships at the Paris, Meudon, and Nice observatories. Twenty-eight years old at the time of the Bolshevik Revolution, soon thereafter Fesenkov organized in Moscow the first State Astrophysical Institute (1923), which he headed until its reorganization (*en masse* with two other bodies) into the Shternberg State Astronomical Institute [GAISh]. During the bloody years of Stalin's Great Terror, while the Pulkovo Observatory lost its entire leadership, Fesenkov was protecting GAISh. After the beginning of the Great Patriotic War (Hitler's invasion of the USSR in the course of World War II), he launched the Institute of Astronomy and Physics in the city of Alma Ata (now Almaty in the Republic of Kazakhstan), creating a safe haven for a number of astronomers to maintain their research during wartime. After the war, Fesenkov's institute continued to preserve its scientific significance, and the founder remained its director until 1964.

Fesenkov was very active within the Committee on Meteorites, Soviet Academy of Sciences, and for decades after 1945 was its chairman. He founded the main scientific journal on astronomy in Russian, the *Astronomical Journal of the USSR*, and for four decades remained its editor-in-chief.

In Soviet times, contrary to many other high-ranking administrators, Fesenkov was hailed as a humane and trustworthy person. A defender of scientific interests of astronomy, he was often eager to help people in trouble.

Starting in 1907, as a student at Kharkov, Fesenkov was inspired by objects found and processes observed within the Solar System. Throughout his entire life, he remained devoted to astrophysical investigations of various aspects of the Solar System, including both the problem of its origin and the emergence of life. Much of his research involved the cosmogony of interplanetary dust and gas.

Fesenkov arranged numerous expeditions for observation of solar eclipses and other astronomical phenomena both within the territory of the USSR and abroad. Being a professor of Moscow University, he nurtured and raised a group of devoted Soviet astrophysicists. Fesenkov never added his signature to the works of his young disciples.

Fesenkov did not make pronounced breakthroughs in astronomy; however, for the time, his results were essential, and many colleagues recalled that his overall positive impact on the climate of Soviet astronomy and its dynamics was very significant. Craters on both the Moon and Mars have been named for him.

Alexander A. Gurshtein

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Oparin, A. I. and V. G. Fesenkov (1961). *Life in the Universe*, foreword by Harlow Shapley, translated from the Russian by David A. Myshne. New York: Twayne.

Fèvre, Jean Le

Born **Lisieux, (Calvados), France, possibly 9 April 1652**
Died **Paris, France, 1706**

Jean Le Fèvre was a calculator for the first official French ephemerides. Le Fèvre is reputed to have begun his career as a weaver. Around 1680, he was associated with a professor of rhetoric at the Collège de Lisieux, who was also an amateur astronomer. The latter had connections with **Jean Picard** and **Philippe de la Hire**, who were working on the first French ephemerides, the *Connaissances des temps*, and Le Fèvre was employed to help in the massive project of calculation of planetary, lunar, and solar positions. On their recommendation, he was elected a member of the Académie des sciences for this work. Besides doing astronomical calculations, he helped La Hire with surveying the French coastline. When La Hire published his *Tabulae astronomicae* in 1687, however, Le Fèvre accused him of plagiarism, and when La Hire's son was commissioned to draw up new astronomical tables by the academy, a task for which Le Fèvre believed he was better fitted, Le Fèvre composed a preface to *Connaissances des temps* attacking both father and son. The government ordered the preface to be replaced, and Le Fèvre was removed from the academy in 1701 on the pretext of nonattendance. He continued to publish ephemerides under the pseudonym J. de Beaulieu. There is no modern edition of Le Fèvre's writings.

Stephen Gaukroger

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Finck, Julius

➔ **Fényi, Gyula**

Finé, Oronce

Flourished **France, 1494–1555**

Oronce Finé was a French mathematician, physician, cartographer, and horologist. He was also in and out of prison. Finé proffered the idea of using lunar eclipse timings to determine longitude.

Alternate name

Orontius Finaeus

Selected Reference

Bennett, James and Domenico Meli (1994). *Sphaera Mundi: Astronomy Books in the Whipple Museum 1478–1600*. Cambridge: Whipple Museum of the History of Science.

Finlay, William Henry

Born **Liverpool, England, 17 June 1849**
Died **Cape Town, South Africa, 7 December 1924**

While working as **Edward Stone**'s first assistant at the Royal Observatory, Cape Town, William Finlay discovered the great September comet of 1882 (C/1882 R1).

Selected Reference

"William Henry Finlay." *Monthly Notices of the Royal Astronomical Society* 85 (1925): 309–310.

Finlay-Freundlich, Erwin

➔ **Freundlich, Erwin**

Finsen, William S.

Born **Johannesburg, South Africa, 28 July 1905**
Died **Johannesburg, South Africa 16 May 1979**

South African William Finsen observed southern double stars, at the Republic (or Union) Observatory, for 55 years. In doing so, he continued the tradition established there by **Robert Innes** and **Willem van den Bos**.

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Anon. (1979). "Double Star Observer." *Sky & Telescope* 58, no. 2 : 137.

Fisher, Osmond

Born **Osmington, Dorset, England, 17 November 1817**
Died **Huntingdon, England, 12 July 1914**

After **George Darwin** proposed that the Moon was formed by fission from the Earth, British geologist Reverend Osmond Fisher added (in 1882) that evidence of this event still may be at hand: He proposed the Pacific Ocean as the scar left over from the violent separation. The Darwin–Fisher fission theory was *de rigueur* early in the 20th century.

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Fisher, Willard James

Born **Waterford, New York, USA, 29 September 1867**
Died **Cambridge, Massachusetts, USA, 2 September 1934**

Willard Fisher did pioneering work in the photography of meteors and collected much valuable data by measuring all meteor photographs housed at Harvard University.

Fisher was educated at Amherst College (BA, Physics: 1892) and Cornell University (Ph.D., 1908). He held lectureships in physics at Cornell, New Hampshire College, and the University of the Philippines before his appointment at Harvard College Observatory in 1922 (as Research Associate in 1927). In 1928 Fisher became a Lecturer in Astronomy.

Fisher's lunar eclipse classification is an alternative to the Danjon Scale.

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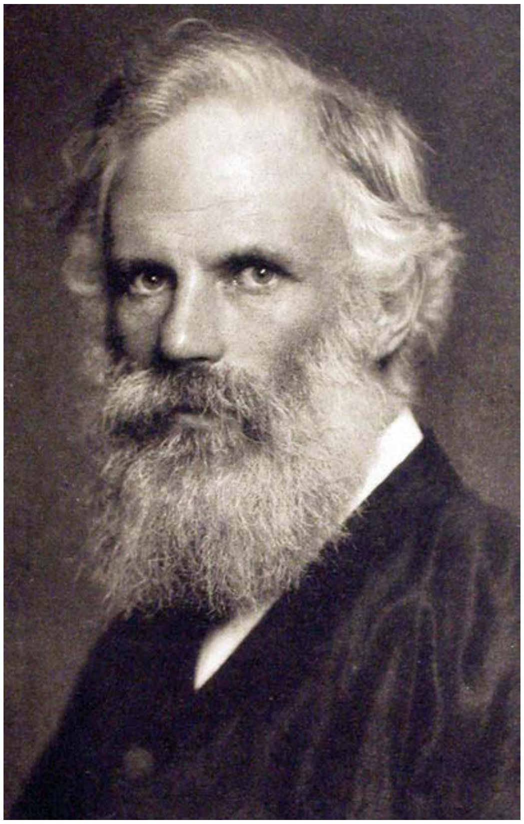
Poggendorff, J. C. (1937). "Fisher." In *Biographisch-literarisches Handwörterbuch*. Vol. 6, pp. 757–758. Berlin.

FitzGerald, George Francis

Born **Dublin, Ireland, 3 August 1851**
Died **Dublin, Ireland, 22 February 1901**



George FitzGerald was an eminent physicist noted for developing **James Maxwell**'s electromagnetic theory of radiation and for his explanation of the null result of the Michelson–Morley experiment.

George was the second of three sons of William FitzGerald, a clergyman in the (Anglican) Church of Ireland and professor of moral philosophy and ecclesiastical history at Trinity College, Dublin, and of Anne Francis, sister of the physicist **George Stoney**. William later became Bishop of Cork and then of Killaloe, County Clare. When George was eight and living in Cork, his mother died. He and his siblings were educated by Charles Harper and the family governess, Mary Anne Boole, sister of mathematic George Boole, in a home where metaphysics, science, and mathematics were highly regarded.

FitzGerald graduated from Trinity College in 1871, at the top of his class in both mathematics and experimental physics. He spent the next 6 years preparing for the fellowship examination and was successful in 1877, on his second attempt. In 1881, FitzGerald was appointed Erasmus Smith Professor of Natural and Experimental Philosophy, holding the chair until his death. In 1885, he married Harriette Mary, second daughter of John Hewitt Jellett, provost of Trinity College.

Electromagnetic theory, as formulated by Maxwell in his 1873 *Treatise on Electricity and Magnetism*, was in a crude and rudimentary form, but FitzGerald recognized its potential. In 1876, FitzGerald heard that the Glasgow physicist, John Kerr, had discovered that the polarization of light was altered by reflection from the poles of a magnet, and he sent a short paper to the Royal Society, refereed by Maxwell. Two years later FitzGerald combined James MacCullagh's wave theory of light with Maxwell's theory to explain the Kerr effect. His two papers on "The Electromagnetic Theory of the Reflection and Refraction of Light" established him as a theoretical physicist. With **Oliver Lodge**, Oliver Heaviside, **Joseph Larmor**, and Heinrich Hertz, FitzGerald developed Maxwell's equations into the form we know today.

In 1882, FitzGerald suggested a means for producing electromagnetic waves but failed to make them himself. When Hertz succeeded in 1888, FitzGerald brought this discovery to the attention of the British Association for the Advancement of Science, thereby ensuring its significance was appreciated.

In spring 1889, FitzGerald, on a periodic visit to Lodge, discussed the failure of the 1881 experiment of **Albert Michelson** and **Edward Morley** to detect the ether. As they sat talking, FitzGerald had the brilliant idea that the motion of bodies through the ether might cause them to change in size by just the amount needed to account for Michelson and Morley's null result; he soon sent a letter to *Science* under the title "The Ether and the Earth's Atmosphere." FitzGerald was unaware that the letter was published, and it remained forgotten until 1967. **Hendrik Lorentz** hit upon the same idea late in 1892, and he developed it fully in conjunction with his theory of electrons. The effect is now known as the FitzGerald–Lorentz contraction and is one of the consequences of **Albert Einstein**'s theory of relativity, which led to the concept of the ether being abandoned.

In astronomy, FitzGerald advised William E. Wilson on solar research that he carried out at Daramona House, County Westmeath, in the 1880s and 1890s. Wilson produced the first reliable estimate of the temperature of the solar photosphere. (His final value of 6,863 K compares favorably with modern estimates.)

In 1892, FitzGerald assisted amateur astronomer **William Monck** to make the first photoelectric measurements of starlight. The detector was a photovoltaic cell of selenium made by George M. Minchin, and the charge was measured with an electrometer loaned by FitzGerald. The actual measurements of the brightness of Jupiter and Venus were made by Monck and Stephen M. Dixon with Monck's telescope in Dublin on 28 August 1892. Then followed a series of stellar measurements made with Wilson's 24-in. Grubb reflector at Daramona in April 1895 and January 1896. Wilson and Minchin operated the telescope, and FitzGerald attended to the electrometer.

In 1893, FitzGerald suggested that geomagnetic storms might be due to electrified particles emitted by the Sun. In 1900 he speculated that the Earth might have "a minute tail like that of a comet directed away from the Sun," what is now called the magnetosphere. He also suggested that comets' tails, aurorae, the solar corona, and cathode rays were closely allied phenomena. In a letter to the *Astrophysical Journal* in 1898, FitzGerald urged American astronomers to measure the velocities of meteors by placing a rotating toothed wheel in front of a camera.

FitzGerald was a keen athlete and gymnast. He played a leading role in the Dublin University Experimental Science Association [DUESA], founded in 1878, which held monthly meetings with short presentations and demonstrations. In 1895 he bought a Lilienthal glider and his attempt to fly in College Park earned him the sobriquet "Flightless FitzGerald."

FitzGerald was elected a fellow of the Royal Society in 1883 and was its royal medallist in 1889 for his work in theoretical physics. He was made an honorary fellow of the Royal Society of Edinburgh in 1900. He acted as honorary secretary of the Royal Dublin Society from 1881 to 1889 and introduced many of his ideas at its regular scientific meetings and was active in the British Association for the Advancement of Science. A 110-km-diameter lunar crater at 27°.5 N, 171° W is named for him.

Both as tutor and professor, FitzGerald strove to improve the teaching of experimental physics in Trinity College but was hampered by lack of funds. He obtained a disused chemical laboratory and introduced practical work into the curriculum. He was always ready to advise and encourage, and in particular three of his students went on to distinguish themselves in science: John Joly, Frederick Trouton, and Thomas Preston. From 1898, FitzGerald took an active part in educational affairs in Ireland serving on boards for national, intermediate, and technical education. Overwork eventually took its toll on his health. A recurrent digestive problem became more serious in autumn 1900, and he died after an operation for a perforated ulcer, leaving a young family of three sons and five daughters.

Ian Elliott

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Hunt, Bruce J. (1991). *The Maxwellians*. Ithaca, New York: Cornell University Press.

Fixlmillner, Placidus

Born **Achleuthen near Krensmünster, (Austria), 28 May 1721**
Died **Krensmünster, (Austria), 27 August 1791**

Placidus Fixlmillner was an observatory director and observer who worked on the orbit of the newly discovered planet Uranus. Fixlmillner was the nephew of Alexander Fixlmillner, the Abbot of Krensmünster. Placidus displayed a talent for mathematics while studying at the monastery school from 1729 to 1735. After studying philosophy, music, and mathematics at Salzburg from 1735 to 1737, he joined the Benedictines in 1737 and then studied theology and foreign languages from 1740 to 1745, during which time he received his doctorate in theology. Fixlmillner spent his entire professional career at the college associated with the Krensmünster abbey, where he served as professor of canon law (1746–1787) and dean of higher studies (1756–1787). For his work in the former position, he was named a notary Apostolic to the Roman Court, a position he held until his death. In 1756, Fixlmillner published the short theological work *Reipublicae sacrae origines divinae*.

A year after his interest in mathematics was rearroused by the transit of Venus that occurred in 1761, Fixlmillner was appointed director of the observatory (atop a nine-story building) that his uncle had established at the monastery, a position that he also held until his death. Fixlmillner described the observations that he made to establish the latitude and longitude of the observatory in his *Meridianus speculae astronomicae cremifanensis* (1765), and he summarized 10 years of observations in *Decennium astronomicum* (1776). Shortly after his death, his successor P. Thaddaeus Derflinger arranged for the publication of Fixlmillner's *Acta Astronomica Cremifanensia* (1791), which among other things, described his observations from 1776 to 1781 and included essays on the parallax of the Sun, the 1769 transit of Venus, the occultation of Saturn in 1775, sunspots, stellar aberration, and planetary aberration and nutation.

Fixlmillner is best known for his work on the determination of the orbit of the planet Uranus after it was optically discovered by the English astronomer **William Herschel** on 13 March 1781. In 1784, Fixlmillner computed elements for its orbit based on both suspected prediscovery observations of the planet made by the English astronomer **John Flamsteed** on 13 December 1690 (an object designated 34 Tauri) and the German astronomer **Tobias Mayer** on 25 September 1756 (an object designated Mayer 964) and the post-discovery opposition observations made by **Pierre Méchain** on 21 December 1781 and Fixlmillner himself on 31 December 1783. Taking account of aberration and nutation in reducing the heliocentric position of 34 Tauri to the time of Flamsteed's observation, he then applied his computed elements to 140 observations and worked out the residuals. The residuals in both latitude and longitude were in general relatively small, except for five that were between 20 and 30 s. The German astronomer **Johann Bode**, who also found a good agreement of Fixlmillner's elements with observations, arranged for a seven-page set of the latter's tables of the motion of Uranus to appear in the *Berliner Astronomisches Jahrbuch* for 1789 (published in 1786).

On 7 July 1788, however, Fixlmillner reported to Bode that his tables were showing greater deviation from observation: 33 s at the opposition of 13 January 1787 and an even larger amount at the one of 18 January 1788. Following a suggestion made by the astronomer Abbé **Francis Triesnecker** of Vienna, Fixlmillner carefully studied the errors in Flamsteed's mural quadrant in order to correct the transit time of the latter's observation for instrumental effects. Fixlmillner discovered that calculations based on the corrected Flamsteed position and Mayer's coordinates produced a slower mean motion for Uranus than those based on recent observations. In other words, his elements for the motion of Uranus could satisfy for an extended period either the prediscovery or the postdiscovery observations, but not both. In 1789, Fixlmillner calculated new elements for the motion of Uranus based solely on Mayer's position, and the 1787 and 1788 opposition observations, and found residual errors no greater than 10 s. Many astronomers, however, recognized Flamsteed as a very careful observer, and the problem of reconciling the position of his 1690 observation to theories of the planet's motion would persist until 1846, when the optical discovery of the planet Neptune confirmed predictions by the French mathematician **Urbain Le Verrier** and the English mathematician **John Adams** that Uranus's motion was being perturbed by a trans-Uranian planet.

Craig B. Waff

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Grosser, Morton (1962). *The Discovery of Neptune*. Cambridge: Harvard University Press.

Fizeau, Armand-Hippolyte-Louis

Born **Paris, France, 23 September 1819**
Died **Venteuil, Marne, France, 18 September 1896**

Hippolyte Fizeau was a pioneer in astrophotography and is best known for his work on the velocity of light. The eldest son of Louis Fizeau, a pathologist at the Paris Medical School, and Béatrice Fizeau, he entered his father's school in about 1840, but dreadful migraines caused him to abandon medicine for physics. In 1853, Fizeau married Thérèse Valentine de Jussieu (daughter of the botanist Adrien de Jussieu), with whom he had three children.

Fizeau's optical work had an impact on astronomy. While still a medical student in Paris, he improved daguerreotype contrast, sensitivity, and stability, and encouraged by **François Arago** in 1844/1845, he collaborated with **Léon Foucault** to take the first successful daguerreotypes of the Sun, which showed clear limb darkening, indicating that the solar luminous layers were gaseous. In 1848, Fizeau announced how in sound the speeds of source and observer with respect to the transmitting medium affect received frequencies, and extended the results to light. Unknown to Fizeau, **Christian Doppler** in Prague had already discussed this effect in 1842, and had interpreted stellar colors as due to spectral shifts resulting from stellar velocities, which he incorrectly presumed attained many tens of thousand kilometers per second. Fizeau, however, predicted that subtle displacements of the absorption lines in stellar spectra could be used to measure much smaller celestial velocities, and the motion of the terrestrial observer, and this correct prediction underpins much of modern astrophysical inquiry.

In 1849, Fizeau made the first terrestrial measurement of the speed of light using a rotating toothed wheel to chop a light beam into pulses that were projected along a round-trip path from his father's house in Suresnes, west of Paris, to a reflector in Montmartre, almost 9 km away. The result obtained was in rough accord with the then-accepted value, which was determined astronomically from trigonometric measurements of the solar distance and the corresponding light-crossing time derived *via* either eclipses of Jupiter's satellites or the constant of aberration and the length of the year. In 1856, Fizeau's work won the ₣50,000 Triennial Prize recently established by Napoléon III, but an accurate verification of the speed of light and length of the Astronomical Unit using improved apparatus financed by the *Académie des sciences* was not completed. It was only on the eve of the attempts to measure the solar distance from the 1874 transit of Venus that an accurate toothed-wheel experiment was finally executed **by Alfred Cornu**, financed by the Paris Observatory.

Evidence unequivocally contrary to the corpuscular theory of light, and hence supportive of the wave theory, was provided in 1850 by Foucault's experimental demonstration, confirmed 7 weeks later by Fizeau, that light travels slower in water than in air. A prediction of the wave theory, made by **Augustin Fresnel** to account for the constant refraction of stellar positions observed by Arago through a prism, irrespective of the terrestrial velocity, was that a transparent medium of refractive index n moving at speed v partially drags the ether with it, by an amount $(1-(1/n^2))v$. In about 1850, Foucault and Fizeau failed to detect any drag in air, but in 1851 Fizeau obtained positive results through the interference of two beams that passed in opposite directions through water flowing as fast as 7 m/s. The result was confirmed 35 years later by **Albert Michelson** and **Edward Morley**. The ether drag is one of several phenomena that were puzzling to classical physics and that ultimately led to the development of the special theory of relativity.

Reserved and moody, and with an independent income, Fizeau never held any significant official post. He became reclusive after his wife's premature death in 1863, but continued to work. Of interest to astronomy are his 1868 suggestion, attempted by **Edouard Stephan**, and later by Michelson and **Francis Pease**, that stellar angular diameters could be measured interferometrically; and his involvement in the planning and analysis of French photographic observations of the 1874 transit of Venus, whence, for example, the memorial of a Mount Fizeau on the subantarctic Campbell Island.

Fizeau was a knight (1849) and officer (1875) of the *Légion d'honneur*, a member of the *Académie des sciences* from 1860, and a member of the *Bureau des longitudes* in 1878. The Royal Society of London awarded him its Rumford Medal in 1866.

William Tobin

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Flaccus, Albinus

➔ **Alcuin**

Flammarion, Nicolas Camille

Born **Montigny-le-Roi, Haute-Marne, France, 26 February 1842**
Died **Juvisy-sur-Orge, Essonne, France, 3 June 1925**

Nicolas Flammarion was a leading planetary observer and popularizer of astronomy during the late 19th and early 20th century. Flammarion, who walked into the Temple of Urania with a feather duster in his hands, was impelled by a strong desire to communicate his enthusiasm to others. His pleasant and imaginative literary style, which endeared him to a vast audience, stimulated thought and inquiry and established him as one of the more influential popularizers of astronomy at the turn of the 20th century.

Flammarion's father, Etienne Jules, had a small farm near Montigny-le-Roi, the principal center of the department of Haute-Marne, a district characterized by a cold climate and poor soil. His mother Françoise (*née* Lomon), who is said to have "possessed aristocratic tendencies," provided further support for the family by running a small drapery business in the town. She apparently expressed high hopes for her four children, and in the case of Camille, the eldest, entertained hopes he would enter priesthood.

On 9 October 1847, Madame Flammarion made arrangements for 5-year-old Camille to observe an annular eclipse of the Sun by placing a pail of water in front of the house. With the image of the Sun thus reflected, Flammarion was able to follow the progress of the event. A partial eclipse occurred on 28 July 1851; the same arrangement, supplemented by a fragment of smoked glass, gave a more satisfactory view. The interest aroused by these events and the appearance of a naked-eye comet in 1852 intensified the boy's interest in astronomy. A local schoolmaster provided Flammarion his first book on the subject.

In 1856 disaster struck; Flammarion's parents were ruined financially and lost their little property. In search of livelihood, they went to Paris leaving Flammarion behind to continue his studies. Their expenses in the metropolis were high, however, and as the father had only poorly paid employment in a photographic establishment, they reluctantly withdrew their son from school. At the age of 14, Flammarion went to work for an engraver. To advance his education he attended night classes, learned English, and furthered his understanding of geometry and algebra. Then fate intervened: A chance encounter brought about by an illness marked a dramatic upturn in Flammarion's career.

Looking around the poorly furnished room in which Flammarion lived, the doctor treating his illness noticed a little table covered with writing material and a collection of books. What especially caught the doctor's attention was a thick 500-page manuscript entitled *Cosmogonie universelle*. The doctor was so impressed with the manuscript that, on revisiting his patient, he suggested that if Flammarion were to call on **Urbain le Verrier**, director of the Paris Observatory, there was every chance that he would be taken on as a pupil-astronomer. A few days later Flammarion was hired by the Paris Observatory. Unfortunately, Flammarion was temperamentally unsuited to the task. The mechanical drudgery of computation could not be reconciled with his poetic inclinations. Certainly he found the mathematics interesting, but Flammarion longed to observe, to conduct researches of "living interest." His imagination soared among the stars; his eyes looked longingly at the domes that housed the key to his desire. Only Flammarion's pen betrayed his true desire.

In 1861, Flammarion marked his literary debut with *La pluralité des Mondes Habités*. It was well received, and the first edition of 500 copies quickly sold out. Le Verrier, however, was not pleased to be upstaged by a junior member of his staff, and Flammarion was dismissed. Poor and without means of support, he secured the good offices of those opposed to Le Verrier, and in 1862, Flammarion obtained employment as a calculator in the Bureau des Longitudes.

But the reception afforded by his first book had by now attracted the interest of several editors, and within the year Flammarion was heavily immersed in science journalism. He also gave a very successful series of lectures in Paris, the provinces, and other European capitals. In 1874 his second book, *Les Mondes imaginaires et les mondes réels*, was published, and in July of the succeeding year it was followed by *Les merveilles célestes*. In 1877 came *Les terres du ciel*, and in 1880 the famous *Astronomie populaire*, which became a bestseller. Translated into many languages, *Astronomie populaire* did more than any other book to spread interest in astronomy.

In 1883, a wealthy admirer, Monsieur Méret of Bordeaux, offered him his château at Juvisy-sur-Orge, situated about 30 km from Paris. Here Flammarion founded the Juvisy Observatory in which he installed a 9.5-in. (24-cm) Bardou refractor, and in due course, obtained the assistance of **Eugéne Antoniadi** and Felix Quénisset. In essence, the observatory was dedicated like a temple, symbolizing Flammarion's dream of finding evidence of extraterrestrial life, and his fascination with the planets, especially Mars. In 1892, he published *La planéte Mars et ses conditions d'habitabilité*, a compilation and synthesis of all that had been written and conjectured about the planet since 1636. (A second edition appeared in 1909.) Flammarion accepted the maritime view of Mars in which the dark areas were seas and the light areas continents. The orange-red hue of the latter suggested a sterile, sandy environment. But, he argued, was it possible to "condemn a world to a fate of this kind" when all the elements of life are abundantly evident? Accordingly, he attributed the baleful color to vegetation. He did not consider the so called *canali* as due to blind chance, and concluded they were watercourses. The idea of an artificial global circulation system was in no way anathema to Flammarion, at least in 1892.

Flammarion's interests were not solely confined to astronomy. He conducted experiments into psychic phenomena, publishing the results in several books, including *Les maisons hantées* and *La mort et son mystère*, 3 vols. (1920–1921). Between 1867 and 1880, Flammarion made many balloon ascents to study atmospheric phenomena, and in 1871 he published *L'atmosphère*. He wrote extensively on atmospheric electricity, climatology, and vulcanology. At Juvisy, Flammarion carried out experiments to see how plant growth was affected by screens of colored glass; in 1894 an agricultural station was annexed to the observatory. Finally, his background in engraving and artistic ability, coupled with his interest in old books and the history of astronomy, prompted Flammarion to create a frequently reproduced woodcut illustrating a pilgrim poking his head through the point where the Earth joins the celestial sphere to view the heavens beyond the stars. This woodcut is often described as having originated in the 16th century.

In 1887, Flammarion founded the Société Astronomique de France, and served as its first president. He also founded and edited its bulletin, *l'Astronomie*. Flammarion was married twice: in 1874 to Sylvie Petiaux-Hugo, a widow, and following her death in 1919, to Gabrielle Renaudot, an astronomer, who carried on Flammarion's work after his death. Madame Flammarion was still general secretary of the society at the time of her death in 1962.

Richard Baum

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Flamsteed, John

Born **Denby, Derbyshire, England, 19 August 1646**
Died **Greenwich, England, 31 December 1719**

John Flamsteed was the premier star cataloger of his time and the first Astronomer Royal of England. As a youth, his interest in astronomy was sparked by a group of pre-Civil War north-country astronomers including **William Gascoigne**, from whom he learned how to apply eye-piece micrometry and screw-gauge telescope adjustments for accurate measurement. From **Jeremiah Horrocks**'s manuscripts he gained a realistic view of solar-system dimensions as well as (*via* **William Crabtree**) an improved lunar theory.

In 1674, Flamsteed was granted an honorary MA by Cambridge by warrant from Charles II, as appreciation of his useful astronomical studies. Two years later he was appointed the King's Observator, mandated to try and find longitude at sea, a task he could never fulfill. At Greenwich, Flamsteed was provided with an empty observatory and a salary of £100 per annum. Eventually his published stellar positions were accurate within 5″, as his final estimate of the Greenwich latitude at 51° 28′ 34″ was within 4″; **Johannes Hevel**, by comparison, had achieved only ½′ in stellar-position accuracy. Flamsteed doubled the number of known stars. Longitude divisions of the globe came to be marked from his workplace as the first Greenwich Meridian, time was measured from the setting of his clock, and the stars received their numbers from his star catalog of 1725.

From timing the diurnal meridian transits of Sirius, Flamsteed ascertained that the Earth rotated uniformly on its axis. (**Johannes Kepler** had its rate vary seasonally.) On the basis of this, he produced an equation of time that was accurate to about 12 s, as compared with the versions used by **Thomas Streete** and others earlier that had erred by 5 min. Flamsteed became the first to formulate a credible "mean time" as opposed to apparent time, and so Greenwich Mean Time began. Also, he became the first to formulate the Moon's 10′ "annual equation," which presupposed the Earth's isochronous axial rotation. (Kepler had wrapped the two together.)

Flamsteed improved upon Horrock's lunar theory, as well as improved its mean solar–lunar motions. Flamsteed brought this lunar theory – the first British astronomical theory – down from the Midlands and became the main spokesman for it, getting it published in 1673. Observations of lunar diameter at apogee and perigee had convinced him of its veracity. Its errors, however, were too large to be of practical value in finding longitude, and so, despairing, Flamsteed in 1683 advocated study of the satellites of Jupiter as the best way of finding universal time.

Isaac Newton's lunar theory was based on Horrock's as explained by Flamsteed, for which reason French historians have remained doubtful whether his lunar theory was derived from a gravity theory. Flamsteed was the first person (with help from his assistant) to prepare tables based on the Newtonian theory, around 1706; but owing parhaps to his chagrin at not being adequately acknowledged by Newton as the source of both the lunar data and the Horroxian theory, he never acknowledged how effective the theory was. Posthumously, his lunar theory, the tabular procedure for finding lunar longitude based on the Newtonian text – which was the basis of his employment – was found to have disappeared from Greenwich and so was absent from the three volumes of the *Historia Coelestis Britannica*, but made a surprising reappearance in the hands of **Pierre le Monnier** in the 1740s who published it. (It was presumably donated by **Edmond Halley**, Flamsteed's erstwhile friend, and, finally, successor.)

In 1681, Flamsteed published his "Doctrine of the Sphere" containing tables of the Equation of Center for the lunar and solar (*i. e*., of the Earth) elliptical motions, derived from an exact solution of the Kepler Equation, within 1″ or so. Thereby he became the first astronomer to apply Kepler's first and second laws of planetary motion. This was before Newton had started to take seriously Kepler's second law, and when various *ad hoc* procedures were current for constructing these tables.

In his Gresham lecture of May 1681, Flamsteed gave the first-ever British account of the perihelion passage of a comet behind the Sun, that of comet C/1680 V1. Newton decided to reject the latter's view in favor of two separate comets. Owing to its close solar passage, this comet became the first for which a mathematical orbit could be reliably computed, thanks to Flamsteed's exact measurements.

Flamsteed decided to measure right ascension using sidereal time, which later became the "Greenwich Hour Angle." His star-classification procedure became the basis of the Flamsteed numbers used in the British Catalogue for numbering the stars. He became (unknowingly) the first astronomer to log the passage of Uranus.

With no ancient star-maps to consult, Flamsteed brushed up his Greek to read the original **Ptolemy**, and concluded (from arguments about right and left shoulders) that all the human constellation figures had to be turned round and that we perceive the globe of the Universe from the inside. His star maps became the most widely used in Europe in the 18th century. He developed a novel stereographic projection for the maps (the Samson–Flamsteed method).

Flamsteed can hardly be blamed for confounding stellar aberration of the Pole Star (which he discovered), of some 20″ magnitude each year, with the long-sought stellar parallax (due to the Earth's orbit). He published his conclusion in 1697. What Flamsteed found was (as **Giovanni Cassini** pointed out) 90° out of phase from where the parallax should have been. In contrast, his ascertaining of solar parallax (half the angle subtended by Earth from the Sun) of 10″, the correct value being 9″, was of profound importance. Horrocks had estimated it as 15″, while **Tycho Brahe** retained the ancient value of 3′. Solar distance relied upon this value. In Flamsteed's words, "The Sun is and ever was above ten times more remote than commonly esteemed."

Flamsteed assured Newton that Jupiter's satellites were exactly adhering to Kepler's third law, as appeared at the opening of the *Principia*'s Book III without acknowledgement. He collaborated with Newton to construct seasonally varying atmospheric refraction tables of much-improved accuracy. He composed a history of astronomy (in the preface to his *Historia*) in which he rejected trepidation, whereby the equinoctial points oscillated back and forth against the zodiac, which contemporaries such as **Robert Hooke** and Cassini still accepted, and established the value of precession at 1° per 72 years.

From 1689, when Flamsteed acquired his precision mural arc, he was able to obtain the high-accuracy lunar-transit measurements, wherein Newton discerned the feasibility of an improvement in the theory. Tradition holds that Flamsteed refused to cooperate but in the first half of 1695 when Newton became immersed in the subject Flamsteed kindly supplied him with over 150 high-precision readings (now lost). Newton was unable to derive the lunar irregularities from his gravity theory. Flamsteed became his scapegoat for this and was forbidden to report that he had spent the best part of a year obtaining and processing these data.

Flamsteed's hope for publishing his work, as the century turned, rested on his visually attractive star-maps, which would appeal to the monarch, but the committee set up by Newton to oversee its publication, or possibly stall it, had other ideas. In 1712, **Edmond Halley** published Flamsteed's stolen observations on the justification that Newton needed the lunar data. **Francis Baily** argued against this view on the grounds that Newton had long since finished his lunar work and that there were no grounds to suppose Flamsteed had not cooperated. Baily admired Flamsteed's "piety, integrity, and independent spirit."

Nicholas Kollerstrom

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Flaugergues, Honoré

Flourished **1755–1835**

In 1809, French amateur astronomer Honoré Flaugergues spotted colored "patches" (dust?) on Mars. He also discovered the Great Comet C/1811 F1 (independently discovered by **Jean Pons**).

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Fleming, Williamina Paton Stevens

Born **Dundee, Scotland, 15 May 1857**
Died **Boston, Massachusetts, USA, 21 May 1911**

American data analyst and "computer" Williamina Fleming devised, along with **Edward Pickering**, the first important system for classification of spectra of stars (after the very basic one of **Angelo Secchi**) and classified more than 10,000 stars on that system. She was from a craftsman's family and worked as a pupil-teacher from the age of 14. She married James Orr Fleming in Scotland, and they immigrated to Boston a year later, divorcing after the birth of their first child, whom Mrs. Fleming was left to support. Her first job was as housekeeper in the home of Pickering, the director of Harvard College Observatory. He was aware of her history as a student and teacher so that, when he allegedly criticized the work of a young man at the observatory by saying that his housekeeper could do better, it was not quite the insult it sounds. In any case, he soon employed Fleming at the observatory, first as a copyist and later as a classifier of spectra. She was eventually appointed curator of astronomical photographs, with responsibility for coordinating the work of a dozen other women, which she was said to have done with considerable firmness. Fleming was elected to honorary membership in the Royal Astronomical Society, continuing the tradition pioneered by **Caroline Herschel** and **Agnes Clerke**.

Secchi had found five classes of spectra sufficient for his visual observations, but photographic spectra, even the very low resolution ones with which the Harvard work began, permitted finer divisions. Initially, Pickering and Fleming assigned their stars to 12 types, A to M (omitting J since the ancient Romans did), from simplest looking to most complex, and relegated small numbers of strays to N, O, P, and Q. As time went on, they added a number of groups of peculiar stars, including class R (now recognized as chemically peculiar), novae, and several types of eclipsing and pulsating variables (then thought to be eclipsers and other sorts of binaries). The first Draper Catalogue (published in 1890 under Pickering's name but with a very large fraction of the work attributable to Fleming) contained 10,498 stars, using all types from A to Q, except N. (None of these, also now known to be chemically peculiar, were bright enough for the eighth magnitude cut-off).

Improved telescopes soon led to spectra with better wavelength resolution and a catalog (published by Pickering and Fleming in 1897) of the stars in seven open clusters. Types C, D, I, and L had disappeared, and Pickering soon merged E, with G, and H with K. An important part of that work was the recognition that different clusters are dominated by stars of different types (now understood as an indicator of their ages). The last of Fleming's works, published under her name alone, included her measurements of the apparent brightnesses of another 1,400 stars, as well as their spectral types.

Fleming examined all of the Harvard survey plates as soon as they were acquired. She learned to recognize both novae and Mira type variables from a single spectrogram, without needing a light curve; discovered 10 novae and more than 300 variable stars, for which she estimated the amplitudes of the light curves; and found what seems to be the first spectrum ever photographed of a meteor in 1897 (published under Pickering's name). The second meteor spectrum appeared as hers in 1909/1910, but the spectral features were not identified until after her death, by **Peter Millman** in 1932. Most are iron, and a few chromium, magnesium, and silicon.

Even before the first Draper Catalogue was published, Pickering had already identified other women to improve the Fleming–Pickering classification scheme for stellar spectra, and had put **Antonia Maury** to work on the stars in the Northern Hemisphere and **Annie Cannon** to work on the southern stars. They, too, held the title of "computer" for much of their careers, as did a total of 47 women under the Pickering directorship, beginning with Nettie Farrar (Fleming's predecessor). Many contributed to the Henry Draper Memorial Catalogue, partially funded by his widow, and many were trained by Fleming.

Katalin Kèri
Translated by: *Endre Zsoldos*

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Focas, John Henry

Born **Corfu, Greece, 20 July 1909**
Died **Greece, 3 January 1969**

Greek astronomer J. H. Focas was one of the last great visual observers of the planets. From the National Observatory, Athens, he gradually migrated to France's Pic-du-Midi and Meudon observatories (where at the end of his life he created the International Astronomical Union's Planetary Photographic Data Center) under the influence of **Bernard Lyot**. Focas is best known for his exhaustive study of Mars: photometric, polarimetric, and cartographic.

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Fontana, Francesco

Born **Naples, (Italy), *circa* 1580–1590**
Died **Naples, (Italy), 1656**

Francesco Fontana, who was a leading figure in the revival of interest in observational astronomy that followed in the wake of **Galileo Galilei**'s discoveries, was born some time between 1580 and 1590, though one source specifies 1602. He graduated in law at the University of Naples, but was more interested in the study of the mathematical sciences, and devoted himself to the construction of telescope and microscope lenses.

Fontana claimed to have been using a telescope since 1608, before Galilei, and was one of the first to make and use telescopes of the Keplerian type. These gave better images than earlier makers had achieved, and enabled him to view the gibbous phase of Mars on 24 August 1638.

Fontana noted a spot on Mars and guessed from its changes that the planet rotates on its axis. He also observed the belts of Jupiter, the phases of Venus, and the 1645 transit of Mercury. From his attempts to draw Saturn, it appears he endeavored to understand the true character of its ring system.

On the other hand, markings that Fontana reported on Venus were probably due to faults in his optical system. Moreover, it was Fontana who initiated the history of the apocryphal satellite of Venus, with his observation of 11 November 1645.

Fontana produced a number of rather stylized lunar drawings in 1629/1630, together with a series of more natural renditions in 1645/1646, when he made drawings of the Moon on every day of a lunation. He drew the Full Moon (1646) to a diameter of 24 cm. The major part of his little treatise, *Novae Coelestium Terrestriumque Observationes et fortasse hactenus non vulgatae* (Naples, 1646), is dedicated to the Moon.

Francesco Fontana died of the plague.

Richard Baum

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Fontenelle, Bernard le Bovier [Bouyer] de

Born **Rouen, Seine-Maritime, France, 11 February 1657**
Died **Paris, France, 9 January 1757**

Bernard de Fontenelle was a scientific popularizer best known for his work on the plurality of worlds. Fontenelle was a polymath, an intellectual, and a man of letters. A nephew of the French dramatist Corneille, he made his early reputation in Rouen as a salon poet and wit. His father was a barrister at the *Parlement* of Normandy. Fontenelle attended the Jesuit college at Rouen, where he began to write poetry, and trained for the law but abandoned the profession after losing a case. He competed for the poetry prize of the French Academy on several occasions without success. He had no more success as a dramatist.

In 1681 he produced *La comète*, an amusing satire inspired by the Great Comet C/1680 V1, in which contemporary explanations of the phenomenon are upheld to ridicule. In the work it is possible to see the burgeoning of what was to make Fontenelle famous: His aptitude for popularizing scientific knowledge and his skepticism of all preconceptions.

These preoccupations were completely unveiled in 1686 by the appearance of Fontenelle's most famous and frequently published and translated work, *Entretiens sur la pluralité des mondes*. This is a lucid exposition of the principles of astronomy as formulated by Claudius **Ptolemy, Nicolaus Copernicus,** and **Tycho Brahe,** enlivened by speculations on the possibility of other inhabited worlds, veined with strands of Cartesian thought, and elegantly presented in the form of after-dinner conversations with a marquise. The work enjoyed huge success, and is notable for being the first learned work in French to be placed within reach of the intelligent but nonspecialized layperson.

In 1702, Fontenelle joined the society appointed to oversee publication of the *Journal des sçavans*. He subsequently received many academic honors, and on 9 January 1697 became permanent secretary of the Académie des sciences (being confirmed in that position in 1699). His later writings are chiefly of a scientific and mathematical nature or connected with the academy. He was elected to the Royal Society of London (1733), the Berlin Academy (1749), and many other such bodies. Fontenelle had tireless intellectual curiosity and believed in the tenets of the Enlightenment: the only way forward in a world where everything is subject to rational explanation is through reason supported by experiment.

Richard Baum

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Forbush, Scott Ellsworth

Born **Hudson, Ohio, USA, 10 April 1904**
Died **Charlottesville, Virginia, USA, 1984**

American cosmic-ray physicist Scott Forbush gave his name to Forbush decreases, the decline in intensity of galactic cosmic rays reaching the Earth's surface during geomagnetic storms. Both are now known to be caused by blasts of high-energy particles reaching us from solar flares.

Forbush's mother, a teacher, enrolled him in the Western Reserve Academy, from which he graduated in 1920. In 1921, he enrolled at the Case School of Applied Social Science, receiving a B.Sc. in physics in 1925. After one year each as an assistant at Ohio State University and as a junior physicist at the National Bureau of Standards, his interest in observational geophysics led him to eventually join the staff of the Department of Terrestrial Magnetism [DTM] of the Carnegie Institution of Washington in 1927, which marked a turning point in his professional life.

Forbush served as an observer for 2 years at DTM's magnetic observatory at Huancayo, Peru, and then on the staff of the *Carnegie*, a nonmagnetic sailing ship in Apia, Western Samoa. In 1931, on returning to Washington, he took a year's leave of absence to attend John Hopkins University where he resumed graduate courses in physics and mathematics with fresh insight drawn from his experiences in the field.

In 1932, Forbush married Clara Lundell, a concert pianist, who died in 1967. During World War II, he served first as a civilian with the Naval Ordnance Laboratory and then in the Office of Scientific Research and Development.

Forbush's career is distinguished by his foundational and outstanding contributions to the field of solar–interplanetary–terrestrial physics resulting from his lifelong study of the relationships among solar activity, geomagnetic storms, and variations in cosmic-ray intensity and his meticulous and painstaking analysis of geophysical data and gravity observations. A brief paper published in 1937 described his observations of decreases in cosmic-ray intensity during magnetic storms; such phenomena came to be designated as Forbush decreases. One of his most significant publications was a review article published in 1966 in the *Handbuch der Physik,* describing much of his life's work. Forbush's Peru and Iowa lectures, and his original published papers, were compiled into a monograph by **James Van Allen** in 1993.

Forbush was awarded the Sir Charles Chree Medal and Prize in 1961 by the Institute of Physics and the Physical Society (London), the John A. Fleming Award of the American Geophysical Union in 1965, and the Waring Prize of Western Reserve Academy. In 1962, he was elected to the National Academy of Sciences and also granted an honorary doctorate from the Case Institute of Technology. Forbush was a fellow of the American Physical Society, the American Geophysical Union, the American Association for the Advancement of Science, and the Washington Academy of Sciences and was president of the Washington Philosophical Society in 1953. In 1970, Forbush married Julie Daves and moved to Charlottesville, Virginia, in 1982.

Raghini S. Suresh

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Ford, Clinton Banker

Born **Ann Arbor, Michigan, USA, 1 March 1913**
Died **Wilton, Connecticut, USA, 23 September 1992**

Though trained as a professional, Clinton Banker Ford's career in astronomy was primarily as an amateur astronomer. He completed all requirements for a Ph.D. at Brown University except his dissertation. After his research was interrupted for service in World War II, Ford worked for a period as an applied physicist. However, his success as an investor allowed him to retire from employment at a very early age and pursue variable star astronomy full-time as a leisure activity. Ford contributed over 60,000 variable star observations to the American Association of Variable Star Observers [AAVSO] archives, but his impact on the organization was profound in many other ways. Ford served as AAVSO secretary for 44 years and as its president in 1960/1961. He was active in preparation of charts to aide variable star observers, drafting hundreds of preliminary charts to start new program stars. In 1987, Ford donated a building to the AAVSO for use as its headquarters in Cambridge, Massachusetts, and left a substantial endowment to support AAVSO activities in perpetuity.

Thomas R. Williams

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Foucault, Jean-Bernard-Léon

Born **Paris, France, 18 September 1819**
Died **Paris, France, 11 February 1868**

Jean Bernard-Léon Foucault determined an accurate value for the speed of light, designed a pendulum to demonstrate the Earth's rotation, invented the knife-edge test, and applied a silvering technique for mirrors that concerning revolutionized telescope optics. He was the son of Jean Léon Fortuné Foucault, a well-off publisher–bookseller, and Aimée Nicole Foucault (*née* Lepetit). He never married. Around 1840, Foucault entered the Paris Medical School, reportedly with the intention of capitalizing on his great dexterity by becoming a surgeon, but he later abandoned medicine for physics, earning his doctorate in 1853.

Much of Foucault's early work was inspired by **François Arago**, director of the Paris Observatory, and was undertaken in collaboration with **Hippolyte Fizeau**. The first successful daguerreotypes of the Sun, taken by Foucault and Fizeau in 1844/1845, showed clear evidence of limb darkening, contrary to Arago's photometric observations, indicating that the outer solar layers were gaseous rather than solid or liquid.

Foucault and Fizeau worked independently after quarrelling during their attempt to conduct an experimental test (suggested by Arago) to discriminate between the particulate and wave theories of light. They split a light beam into two, passed each through several meters of either air or water, and used a small, fast-spinning mirror to convert the temporal separation between them into an easily measureable angular deviation. In the spring of 1850, Foucault found that light traveled more slowly in water than in air, as predicted by the wave theory, signaling the final demise of the already moribund corpuscular theory.

In 1851, Foucault devised his eponymous pendulum experiment consisting of a freely oscillating bob, the swing plane of which appears to veer slowly clockwise, as seen from above by a terrestrial observer in the Northern Hemisphere, while the Earth rotates anticlockwise beneath. Informed opinion had become fully convinced of the Earth's diurnal rotation in the decades following the publication of **Isaac Newton**'s *Principia*, but Foucault now provided clear dynamical evidence of it, equivocal results having been previously obtained from experiments such as dropping weights down mineshafts. At the poles, the swing plane of the Foucault pendulum remains fixed relative to the inertial frame defined by the distant stars, but elsewhere, because the direction of the gravitational restoring force changes as the Earth rotates, the swing plane is not locked to the motion of the celestial sphere but to the component of this motion around the horizon. After one sidereal day the swing plane does not return to the same orientation, except at the poles; instead, the rotational period of this pendulum equals the Earth's 24-hour (sidereal) day divided by the sine of the pendulum's latitude. Public confusion over the sine term led Foucault to devise (and name) the gyroscope in 1852, whose freely suspended spin axis locks directly to the celestial sphere and provides a conceptually clearer demonstration of terrestrial rotation. Mechanical gyroscopes were of importance in navigation through most of the 20th century but have now mostly been superseded by optical gyroscopes.

In 1855, Foucault was appointed "physicist" at the Paris Observatory under its new director **Urbain Le Verrier**. There, Foucault devised optical tests that allowed him to polish large glass mirrors for reflecting telescopes, which were made reflective by a coating of chemically-deposited silver. His most famous test, the knife-edge test, reveals in exaggerated relief the figuring faults of lenses and mirrors, which can then be corrected through additional polishing; amateur telescope makers today continue to use this technique. Foucault's largest telescope, which incorporated an 80-cm-diameter mirror, was installed at the Marseilles Observatory in 1864. It was equatorially mounted and also included a Foucault-designed governor for sidereal tracking. Although the knife-edge test was a crucial development for construction of large, fast reflecting telescopes, it was not until almost the 20th century and the rise of spectroscopy and astronomical photography that reflectors displaced refracting telescopes as astronomers' instrument of choice.

In his last experiment of consequence, Foucault modified his spinning-mirror apparatus to make the first accurate laboratory measurement of the speed of light. From analysis of planetary motions, Le Verrier had concluded that the distance from Earth to the Sun was about 3% smaller than generally accepted. At the time, the speed of light derived from astronomical measurements; the procedure's largest uncertainty by far involved the size of the astronomical unit, so Le Verrier predicted that the speed of light was also 3% smaller than the then-accepted value of 310,000 km/s. Foucault confirmed this prediction in 1862, obtaining a result that is also in agreement with the modern value of the speed of light and the distance to the Sun.

Foucault's last years were spent working on mechanical governors, which he hoped would make his fortune, and a siderostat for solar observations. This work was cut short by his premature death from what was probably a case of rapidly progressing multiple sclerosis. He is buried in the Montmartre Cemetery, Paris.

Foucault was awarded the Copley Medal of the Royal Society of London in 1855. He was made a knight of the *Légion d'honneur* in 1850, and officer in 1862. Foucault was a member of the French Bureau des longitudes from 1862 and the Académie des sciences from 1865. Additionally he was a foreign or corresponding member of numerous academies.

William Tobin

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Fouchy, Grandjean de

➔ **Fouchy, Jean-Paul**

Fouchy, Jean-Paul

Born **Paris, France, 17 March 1707**
Died **Paris, France, 15 April 1788**

Jean-Paul Fouchy was the inventor of the analemma and an observational astronomer. He was the son of Philippe Grandjean, from an old Mâconnais family, who came to Paris as an engraver–printer, and of Marie-Madeleine Hynault. Philippe invented the font "Grandjean." Their son was educated to follow his father's trade and began as an engraver–printer. Fouchy turned away from engraving and began to study science. In 1724, he was a pupil of **Joseph Delisle**. By 1727, Fouchy became a member of the Society of Arts under the patronage of the Count of Clermont. This society wished to apply scientific principles to artistic practice.

In 1730, Fouchy invented the analemma. This is a figure-eight curve that one draws around the straight meridian line. For any day of the year, the distance between the curve and the meridian line provides the difference between true noon and mean solar noon. He probably first drew one on the wooden floor of the Count of Clermont's salon (now the restaurant room of the Sénat at the Petit Luxembourg). It has since disappeared, and Fouchy's memoir is lost.

Fouchy and his first wife, born de Boistissandeau, had a daughter. From his second wife, born Desportes-Pardeillan, he had a daughter and two sons who followed military careers.

On 24 April 1731, Fouchy was named assistant astronomer at the Académie royale des sciences in Paris, then associate in 1741. His astronomical memoirs during this period included a proposal for more convenient forms for ephemerides tables, a method to observe the transits of Mercury, and a means to improve the backstaff. In addition, Fouchy was thinking of searching for the cause of the inequalities of the Jupiter satellite eclipses based on the laws of optics, but it was **Jean Bailly** who followed up on this subject.

In 1744, Fouchy became perpetual secretary of the academy, succeeding **Jean de Mairan**. In this function, he wrote the *éloges* of his deceased colleagues for some 30 years. He resigned this post in 1776, handing it over to his assistant M. J. A. N. Condorcet.

During his years as perpetual secretary, Fouchy's astronomical work was reduced to eclipses and Venus transit observations. He also took meteorological observations. After retirement, he published a few memoirs on instruments, but with little impact.

Fouchy was a respected member of the academy and a member of several others, including the Royal Society of London. In addition to doing his academy work, he acted as auditor of accounts and ordinary secretary to the Duc d'Orléans. A poet, he also liked music and played several instruments.

Simone Dumont

Alternate name

Fouchy, Grandjean de

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Fourth Earl of Rosse

➤ **Parsons, Laurence**

Fowler, Alfred

Born **Wilsden, (West Yorkshire), England, 22 March 1868**
Died **Ealing, (London), England, 24 June 1940**

British spectroscopist Alfred Fowler was the first to produce in the laboratory the spectral line at 4686 Å due to ionized helium and made significant contributions to the understanding of the spectra of ionized gases in general. He was the seventh son of Hiram and Eliza Hill Fowler and married Isabella Orr in 1892. She and their son and daughter survived him.

Fowler was educated at local schools, starting at the Normal School of Science (later the Royal College of Science) in South Kensington (near London), where he studied mechanics. In 1885, he began work as a research student at the Solar Physics Observatory [SPO] under **Norman Lockyer**. Fowler held a position as demonstrator at the SPO from 1888 to 1901 when he was appointed to an assistant professorship at the Royal College of Science (still later Imperial College, London). He was appointed to a full professorship in 1920 after Lockyer's death, continuing at the Royal College until his retirement in 1934, and in later years as one of the first two Royal Society research professors. Many of his students followed him into spectroscopy, but the best known was the writer H. G. Wells.

Fowler's work on laboratory, solar, and stellar spectroscopy bridged the transition from pure empiricism to preliminary theoretical understanding provided by the Bohr model of the atom. Lockyer had made the somewhat radical suggestion that certain spectral lines, called "enhanced," were due to atoms that had been somehow broken up (despite the meaning, "not dividable," of the word atom). "Enhanced" in this context means that the lines were more conspicuous in laboratory spectra produced by short-lived sparks than in spectra produced by electric arcs (and much stronger than in furnace spectra of the same elements). The sequence of strengths suggested a temperature effect; though, as Fowler pointed out in connection with the spectrum of the solar chromosphere, lower density could also enhance these lines. His most important contribution was probably the production of the 4686 Å feature (seen by **William Pickering** in the spectrum of ζ Puppis in 1896) in the spark spectrum of a mix of hydrogen and helium gases in 1912. Two years later, Fowler concluded that "enhanced lines" in general could have their wavelengths calculated from a formula analogous to that for furnace spectrum lines of the next element in the periodic table, but that the Rydberg constant, R, must be replaced by 4R. The example he studied most thoroughly was the spectrum of "enhanced" (ionized) magnesium, with a single electron in its outer shell, and the analogous spectrum of neutral sodium.

On the basis of these considerations, Fowler predicted that there should also be spectral series with constants of 9R and 16R, corresponding to doubly and triply ionized atoms. These were found in laboratory experiments in 1923 by Fowler and by F. Paschen. Among Fowler's other contributions were the first photographs of the flash (chromospheric) spectrum of the Sun during solar eclipses in 1893 and 1898, the first accurate measurement of the wavelength of the green solar coronal line (now known to be radiated by atoms of iron that have lost 13 electrons), and the identification of titanium oxide in the spectra of cool stars, of carbon monoxide in comets, and of magnesium hydride in sunspots (implying that they are cooler than the surrounding photosphere).

Fowler was awarded many prizes in his life, among which were the Valz Prize of the Paris Academy of Science (1913), the Gold Medal of the Royal Astronomical Society (1915), the Royal Medal of the Royal Society (1918), the Henry Draper Gold Medal of the National Academy of Science (1920), and the Catherine Bruce Gold Medal of the Astronomy Society of the Pacific. He was made fellow of the Royal Society in 1910, president of the Royal Astronomy Society (1919–1921), president of Section A of the British Association for the Advancement of Science (1926), and fellow of Imperial College (1935). Fowler was honored with the CBE for his services to science and was elected a foreign associate of the National Academy of Science in 1938. Among his many services in the organization and administration of science, Fowler was the first general secretary of the International Astronomical Union, from 1919.

Nadia Robotti and Matteo Leone

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Fowler, Ralph Howard

Born **Fedsen, Essex, England, 17 January 1889**
Died **Cambridge, England, 28 July 1944**

British theoretical astrophysicist Sir Ralph Fowler is best remembered for being the first to apply the ideas of quantum mechanics to the structure of white dwarf stars, showing that they must be supported by the pressure of degenerate electrons. He was the son of Howard and Frances Eva (*née* Dewhurst) Fowler. His father was an Oxford-educated businessman, and his mother was the daughter of a wealthy cotton merchant. Raised in a childhood of privilege, Fowler received his earliest education from a tutor until the age of ten when he enrolled at the Evans Preparatory School. His academic brilliance began to emerge 3 years later when, following the awarding of a scholarship to Winchester College in 1902, he won school prizes in mathematics and natural sciences. It was particularly Fowler's display of extraordinary mathematical ability that drew attention from his instructors and peers. However, he was by no means a self-absorbed academic. By all accounts he was quite an athlete, very personable and popular with his peers, and possessing natural leadership skills, a keen sense of humor, and a hearty laugh. These personal attributes would serve Fowler well and have had untold influence later in the professional interactions he had with pre and postdoctoral students and colleagues.

Fowler won a scholarship to Trinity College, Cambridge, and received his BA in mathematics in 1911. In 1913, he was awarded the Rayleigh Prize in Mathematics at Cambridge. He took his MA there in 1915.

Graduating in the midst of great peril for his country, Fowler enlisted in the Royal Marines. His family was not spared the ravages of World War I suffered by the general population. He lost his younger brother Christopher, who was killed in action at the Battle of the Somme. Fowler himself was severely wounded by Turkish fire during the Gallipoli campaign. Following his discharge from the armed forces, Fowler became part of an elite research group (the Ordnance Board) working on ballistics problems in warfare. For his contribution to this critical defense work, he was awarded the OBE in 1918.

After World War I, Fowler returned to Trinity College in 1919 as a college lecturer in mathematics. His research at that time was in pure mathematics. At Cambridge he made the acquaintance of **Ernest Rutherford,** and the two became close friends. It was the influence of Lord Rutherford that was, at least in part, responsible for Fowler's shift in interest to problems of thermodynamics and statistical mechanics, and which helped introduce him to the kinetic theory of gases. He eventually married Lord Rutherford's daughter Eileen who bore the couple four children. The oldest, Peter Howard Fowler, was a distinguished cosmic-ray physicist who discovered the presence of both very light elements (lithium, beryllium, and boron) and very heavy ones resulting from r-process neutron captures in cosmic rays. His daughter, C. Mary R. Fowler (Nisbet), is in turn an astronomer and recent past vice president of the Royal Astronomical Society.

In 1922, Fowler began collaborative research with C. G. Darwin on the partition of energy, which led to new techniques involving statistical mechanics to solve problems in physical chemistry. In 1923, he published, with **Edward Milne**, a fundamental paper on stellar spectra, pressures, and temperatures. They used the Saha equation to show how, as a function of stellar temperature, absorption lines would appear, pass through maximum strength, and then disappear again. This result, published in 1923/1924, in turn fed into the thesis of **Cecilia Payne-Gaposchkin**, which demonstrated that stars are made mostly of hydrogen and helium, and marked the beginning of Fowler's seminal astrophysical contributions in a series of papers that won him the Adams Prize of the University of Cambridge. These basic papers formed the basis of his outstanding book on *Statistical Mechanics* published in 1929.

However, in 1926, Fowler's most important and far-reaching work was published linking the degenerate state of a gas obeying quantum (Fermi–Dirac) statistics to white dwarf stars. It is no small indicator of Fowler's preeminence that **Subrahmayan Chandrasekhar**, when offered a special scholarship from the government of India to further his studies in England, chose Fowler with whom to carry out his research. Chandrasekhar's first research paper on quantum statistics was sent to Fowler who, of course, had already applied the new (Fermi–Dirac) statistics to explain white dwarfs.

Fowler's calculation had made use of quantum mechanics but only Newtonian gravitation. Chandrasekhar incorporated at first special and then general relativity into the calculation, thereby establishing the maximum possible mass for white dwarfs. Fowler's other research students included two other Nobel Prize winners (Paul A. M. Dirac and Neville Mott) and ten other fellows of the Royal Society (London). He also influenced **Arthur Eddington** and **William McCrea**.

Fowler continued research on thermodynamics and statistical mechanics into the 1930s, and in 1932, he took a position at the Cavendish Laboratory in Cambridge and was elected to the Plummer Chair in Theoretical Physics. Unfortunately, he developed a serious illness in 1938. As war again loomed in Europe, Fowler once again resumed his defense work with the Ordnance Board, despite his illness, and was selected to become a liaison between the United Kingdom and the United States and Canada. He was knighted in 1942. Fowler continued his work with the Ordnance Board upon returning to the United Kingdom and finally succumbed to his illness.

Edward Sion

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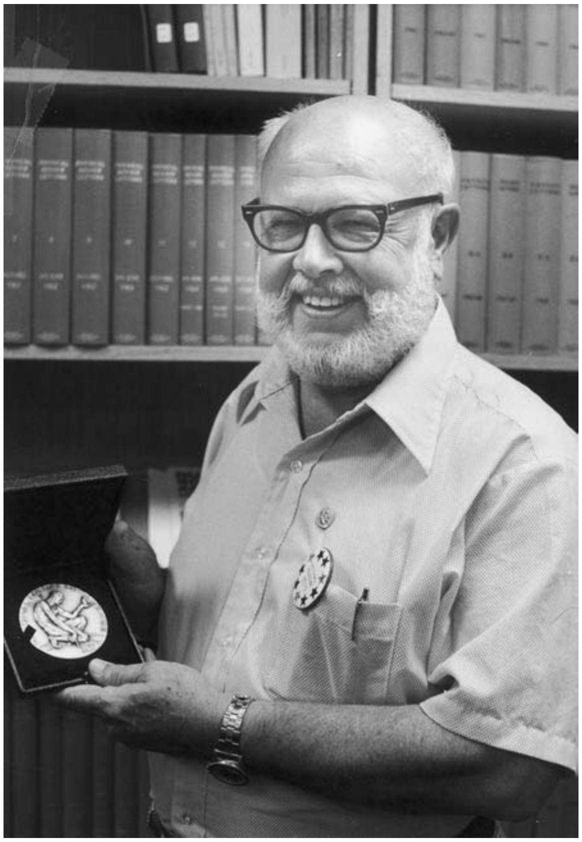

Fowler, William Alfred

Born **Pittsburgh, Pennsylvania, USA, 9 August 1911**
Died **Pasadena, California, USA, 14 March 1995**

The scientific career of William Fowler has enduringly enriched astronomy by providing a systematic treatment of nuclear reaction rates in stars. This achievement earned him the 1983 Nobel Prize in Physics, shared with **Subrahmanyan Chandrasekhar**.

Fowler grew up in Lima, Ohio, where he acquired a lifelong fascination for steam engines. He was valedictorian of his class at Lima Central High School (1929). Enrolling at Ohio State University, Fowler graduated in 1933 with a B.S. degree in engineering physics. He was accepted into the California Institute of Technology (Caltech) as a graduate student in physics. His career was opened (in Fowler's own opinion) by becoming a research student under Charles C. Lauritsen, who had constructed the 750-kV X-ray tube at Caltech's High Voltage (now Sloan) Laboratory. Following the discovery of artificially induced nuclear reactions by John D. Cockcroft and Ernest T. S. Walton, Lauritsen and Fowler became pioneers in particle-induced reactions at low energies. Toward this end, they constructed a new electrostatic accelerator based on the principle of Robert J. Van de Graaff. With it, Fowler discovered radiative capture reactions, which are also important processes occurring inside stars.

Fowler experimentally obtained and systematized nuclear data for astronomy. At Caltech's Kellogg Radiation Laboratory, he measured the rates for nuclear reactions that are understood to occur in stars. This remained his goal for five decades. Personnel from his laboratory not only participated in most of the seminal measurements of the reaction rates for hydrogen, helium, carbon, and oxygen fusion reactions, but also focused on an appropriate theory of low-energy reactions and on the parametric representations of data that would be most useful for astronomers modeling the evolution of stars. Fowler was first and foremost a nuclear physicist, but he came to be known more broadly as a "nuclear astrophysicist."

In 1934, Lauritsen, Fowler, and graduate student H. Richard Crane succeeded in producing a 10-minute period of radioactivity, following the bombardment of carbon nuclei with protons. It was the first measurement of one of the reactions of the CNO cycle in stars, which was itself unknown at the time. Fowler worked on the beta-decay spectrum of radioactive nitrogen-13 and subsequently on the detection of gamma rays emitted when the carbon radioactively captured a proton. **Carl Anderson** and his student showed that the particles emitted by this reaction were positrons, using the same cloud chamber with which Anderson had first discovered the positron as a particle. But the suggested physical process of radiative capture had been a matter of considerable controversy. Three-fourths of the nuclear reactions in the C–N cycle are radiative captures, and Fowler measured them. His 1936 Ph.D. with Lauritsen lay at the center of an emerging science, and his devotion to astrophysics never abated.

The outbreak of World War II put a stop to nuclear physics research at Kellogg Laboratory. Their faculty, which by this time included Fowler and Lauritsen's son, Tom, plunged into the war effort. The Kellogg faculty was moved to Washington (1940/1941) to work on proximity fuses for the detonation of antiaircraft shells. They returned to Pasadena to set up work on solid propellants for rockets at the Naval Ordnance Test Station at China Lake, California. For his public service rendered in wartime, Fowler received the Naval Ordnance Development Award in 1945 and the President's Medal for Merit in 1948.

Immediately after the war, Fowler and the Lauritsens made their decision to study the reactions of light nuclei, with an emphasis on their significance to stars. Their goal was not what is today called "nucleosynthesis," the origin of the chemical elements. Instead, their objective was to understand and quantify thermonuclear power in the Sun and stars. The work of **Hans Bethe** and others had made it clear, however, that nuclear reactions would modify the abundances of light elements. The time was ripe for a theory of nucleosynthesis in stars, which was begun in England by **Fred Hoyle**. Fowler and Hoyle would not meet for some time, but would eventually become one of the foremost teams in the history of astronomy. Many have argued that Hoyle should have shared the 1983 Nobel Prize with Fowler by including the theory of nucleosynthesis in stars. The citation, however, emphasized the *experimental* estimation of stellar nuclear reaction rates, which was Fowler's life work.

In the early 1950s, the big question in Fowler's mind concerned the fusion of helium nuclei. Was a star out of fuel after its hydrogen has been consumed? Nuclear experiments at Kellogg Laboratory showed that no stable nucleus of mass 5 existed. Moreover, their demonstration that beryllium-8 spontaneously broke apart made it clear that no stable nucleus of mass 8 existed. Stellar ions seemed impotent at this impasse. When Edwin E. Salpeter spent one summer (1951) at the Kellogg Laboratory, he implemented an idea of Bethe's, by which a small equilibrium concentration of beryllium-8 could capture a third alpha particle and, with the emission of a gamma ray, transmute to a stable carbon-12. We now call this reaction series the triple-α process; Salpeter correctly proposed it as the energy source for red giant stars.

But when Hoyle visited the Kellogg Laboratory for the first time in 1953, he argued that its capture rate would be inadequate unless carbon-12 was to have an excited state with zero spin and positive parity at 7.7-MeV excitation. Fowler described his reaction to this pronouncement as: "Go away, Hoyle. Don't bother me!" But quietly, Fowler urged that the measurement be made, and Ward Whaling in fact detected the state at 7.68 MeV. Hoyle's prediction of this energy state was, and still is, the most accurate that had ever been achieved.

Hoyle's views on nucleosynthesis in stars also hooked Fowler. With E. Margaret and Geoffrey R. Burbidge, the four published their classic paper, "Synthesis of the Elements in Stars" (1957). It became such an influential paper that it came to be cited, almost like Kepler's Laws, simply as B^2FH (for the authors Burbidge, Burbidge, Fowler and Hoyle). Today, it is known that the details of these mechanisms were not always correctly described, but the overall goal of the paper, its spirit, and its techniques were sound and well stated.

This investigation was begun during Fowler's first sabbatical at Cambridge, England (1954/1955).There, he worked with Hoyle and met the Burbidges, who subsequently spent the following year at Pasadena continuing the effort. Being at the famed Cavendish Laboratory, where **Ernest Rutherford** had dominated nuclear physics throughout the 1920s and 1930s, seemed like working on hallowed ground to Fowler. In 1960, he delivered a historical paper, "Rutherford and Nuclear Cosmochronology," for the Rutherford Jubilee.

In 1957, Fowler began to train students and postdocs in theoretical nuclear astrophysics, as contrasted with pure nuclear physics. By 1961, Fowler moved the Kellogg Laboratory into the wider astrophysical arena by convening the first postdoctoral group dedicated to theoretical nuclear astrophysics. That cohort (1961–1963) comprised John N. Bahcall, Icko Iben, Jr., Richard L. Sears, and the author of this essay. Its weekly colloquium was named the SINS Seminar (for "Stellar Interiors and NucleoSynthesis"), a typically Fowlerian pun. Painstaking experiments on thermonuclear reaction rates were led by Charles A. Barnes, Ralph W. Kavanagh, Tom A. Tombrello, and Ward Whaling. Caltech graduate students and visiting scientists contributed heavily. The entire proton–proton chain, CNO cycle, and helium-fusion reactions were measured under Fowler's supervision.

By the mid 1960s, Fowler's attention had spread to larger nuclear astrophysical issues: solar neutrinos, the creation of iron and nickel in highly evolved stellar interiors, neutrino processes in supernovae, nucleosynthesis in the Big Bang, supermassive stars, and the relativistic astrophysics of quasi-stellar objects and radio galaxies. Much of this expansion of nuclear astrophysics was done in collaboration with Hoyle. After this interest in new applications had run its course, Fowler returned to his original goal, namely that of formulating the most accurate rates for nuclear reactions within stars. Following Hoyle's resignation from Cambridge in 1972, Fowler devoted the rest of his life to the publication of tables of rate coefficients for stellar nuclear reactions.

Fowler felt especially honored by the Astronomical Society of the Pacific's Bruce Medal (1979) and by the Nobel Prize in Physics (1983). In addition, he was awarded the Ohio State University's Lamme Medal, the Liege Medal, the California Scientist of the Year Award, the Vetlesen Prize from Columbia University, the Tom Bonner Prize of the American Physical Society, the Eddington Medal of the Royal Astronomical Society, and election to the National Academy of Sciences (1956). He was chosen president (1976) of the American Physical Society and a member (1968–1974) of the National Science Board. Other recognitions of distinguished public service were the National Aeronautics and Space Administration Apollo Achievement Award (1969), the National Medal of Science (1974), and the *Légion d'honneur* of France (1989). After 1970, Fowler held the title of Institute Professor of Physics, in recognition of his contributions to science at Caltech.

Just before World War II, Fowler married Ardianne Foy Olmstead. The couple had two daughters. Following Ardianne's death in 1988, Fowler married Mary Dutcher.

Donald D. Clayton

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Fox, Philip

Born **Manhattan, Kansas, USA, 7 March 1878**
Died **Cambridge, Massachusetts, USA, 21 July 1944**

During Philip Fox's career as an observatory and planetarium director, he exhibited many traits desirable for a professional astronomer involved in administration and served as a role model for future American planetarium directors.

The son of Simeon and Esther (*née* Butler) Fox, Philip earned a bachelor's degree in 1897 at Kansas State College. After graduation, he taught mathematics and served as commandant at Saint John's Military School before enlisting in the US Army. In 1898, Fox served in the Philippine Islands where he rose to the rank of second lieutenant during the Spanish–American War. After the war, he returned to Kansas State and was awarded a master's degree in 1901. Fox also studied under **Edwin Frost** and earned a second bachelor's degree in physics from Dartmouth College in 1902. The following year, Fox was appointed a Carnegie Assistant at Yerkes Observatory and worked with Frost on its Rumford spectroheliograph until 1905.

After a year of study at the University of Berlin, Fox returned to Yerkes and taught astrophysics until 1909, when he replaced **George Hough** as director of Northwestern University's Dearborn Observatory. Fox continued Hough's program of measuring binary stars with Dearborn's historic 18.5-in. Clark refractor. In 1911, Fox replaced the telescope's tube and mounting with superior equipment that allowed him to extend the observatory program to the photographic determination of stellar parallaxes. During World War I, Fox volunteered for service in the Army, receiving a commission as a major in the infantry. He served in France and was promoted to lieutenant colonel while serving as an assistant chief of staff in the Seventh Infantry Division.

In 1919, Fox resumed his research and teaching at Dearborn Observatory. His investigations grew to involve the help of "no fewer than twenty four assistants and students who had been trained and had taken part in the work." A number of these assistants were women astronomers, but as former Lick Observatory director **Robert Aitken** noted, Fox gave "scrupulous credit … to the part every one of the considerable number had taken." Much of this work appeared in Volume I (1915) and Volume II (1925) of the *Annals of the Dearborn Observatory*, written and edited by Fox. He also completed a study on the rotation of the Sun that was published in 1921.

Fox was chosen as the first director of the Adler Planetarium in Chicago (the first such installation in North America) in 1929. The planetarium was to be situated in close proximity to both the Field Museum of Natural History and the Shedd Aquarium on Chicago's lake front; both institutions fostered active research programs in addition to their public museum roles. Fox envisioned that the planetarium would likewise be operated as a research institution and not simply as a pedagogical device. He installed a coelostat on the planetarium's roof, feeding a vertical telescope with a spectrohelioscope, although this was used primarily for exhibiting the solar spectrum.

Fox and his assistant **Maude Bennot** devised a regularly changing schedule of monthly programs. Twelve lecture topics were developed in order "to show the various possibilities of the [star] instrument." Audience members who attended the series received a complete introductory course in descriptive astronomy. This programming style was dubbed the "American practice" and was emulated by other major US planetaria during the 1930s. Fox wished all visitors "to see a stirring spectacle, … the heavens portrayed in great dignity and splendor, dynamic, inspiring, in a way that dispels the mystery but retains the majesty."

Fox served as master of ceremonies at the opening night of Chicago's Century of Progress Exposition (1933/1934). Light from the star Arcturus was gathered onto photoelectric cells at the Yerkes Observatory (and three other remote astronomical observatories in the event it was cloudy at Yerkes). Electrical impulses from these photoelectric cells were transmitted over telegraph lines and used to turn on lights illuminating the fair's exhibits. Arcturus was chosen on account of its distance of forty light years. Starlight reaching telescopes in 1933 had begun its journey at the time of the World's Columbian Exposition, hosted at Chicago in 1893. During the fair's two seasons, attendance at the Adler Planetarium reached almost 1.3 million visitors. By this means, a large segment of the country's population came to experience a Zeiss planetarium's reproduction of the heavens.

Recognition of Fox's skills as an administrator led to a request for his services in the opening of Griffith Observatory's planetarium in Los Angeles, California. A quarrel between the observatory's board of directors and the project's advisory committee, astronomers associated with Mount Wilson Observatory and the California Institute of Technology, paralyzed the project until Fox arrived on the scene. Nearly a year of temporary duty in Los Angeles was required to see the project on to its successful startup.

During his tenure at the Adler Planetarium, Fox hosted the 44th meeting of the American Astronomical Society (1930) and published volume III of *Annals of the Dearborn Observatory* (1935). He maintained professional ties with numerous scientific associations, serving as secretary (1925–1933) and vice president (1937) of Section D of the American Association for the Advancement of Science and vice president (1938–1940) of the American Astronomical Society. He also served for many years as the secretary of the Chicago Astronomical Society and actively promoted the growth of amateur astronomy and amateur telescope making in the Chicago area. Fox made two journeys to observe total solar eclipses: on 10 September 1923 and 31 August 1932.

A very different type of research came to be associated with the Adler Planetarium. When Fox sailed for Europe to familiarize himself with its principal museums and planetaria, he learned about the sale of an important collection of astronomical instruments by the Amsterdam antiques dealer, W. M. Mensing. Adler's purchase of the

Mensing Collection formed the nucleus of the Astronomy Museum, to which the planetarium's name would thereafter be connected.

In 1937, Fox became the new executive director of Chicago's Museum of Science and Industry. By his own admission, he faced "a task of very considerable magnitude." Although they were devoting up to 6 days a week to the museum in attempting to deal with the administrative burden, Fox and several department heads were summarily dismissed only 3 years later after a change took place in the museum's governing board. An appraisal of Fox's apparent problem with the board was offered by historian Herman Kogan, who noted that "[Fox] seemed less concerned with attracting larger crowds than with converting the Museum into an institution for scholars and educators."

Fox was recalled to active military service in 1940 with the rank of full colonel, and was made commanding officer of the Army Electronics Training Center at Harvard University in 1942. In addition to his administrative duties, Fox also taught electronics. He died from a cerebral hemorrhage.

Fox married Ethel L. Snow of Chicago in 1905. The couple had three sons, Bertrand, Stephen, and Robert, and a daughter, Gertrude. Philip Fox was a skilled violinist, cellist, and organist and also drew, painted, and composed etchings for recreation. Fox was awarded honorary degrees from Drake University (LL.D.: 1929) and Kansas State College (D.Sc.: 1931).

Papers of Philip Fox are held in the Northwestern University Archives, Evanston, Illinois. Fox's planetarium correspondence is preserved at the Adler Planetarium and Astronomy Museum, Chicago, Illinois. Letters between Fox and **George Hale** are found in the microfilm edition, Hale Papers, Carnegie Institution of Washington and California Institute of Technology.

Jordan D. Marché, II

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Fracastoro, Girolamo

Born **Verona, (Italy), 1478**
Died **near Verona, (Italy), 6 August 1533**

Girolamo Fracastoro's one book on astronomy described the apparent motions of the sky, in geocentric terms, but was soon supplanted by **Nicolaus Copernicus**.

Fracastoro studied literature, mathematics, philosophy, astronomy, and medicine in Padua, where he received his degree in 1502 and became instructor in logic. In 1509 he went back to Verona and dedicated himself to his studies. He is more famous for his books of medicine (*Syphilis sive morbus gallicus*, 1530, and *De contagione et contagiosis morbis et curatione*, 1546) than for his astronomical works. But in 1538 Fracastoro wrote *Homocentrica sive de stellis*, where he describes the movements of the celestial spheres, the seasons, and the various types of day (solar and sidereal) and recalls the old theory of **Eudoxus**, which was supplanted by the Ptolemaic theory. This work received little attention because Copernicus published his *De revolutionibus orbium coelestium* in 1543, and the attention of astronomers was then concentrated on the heliocentric theory.

There is a prominent lunar crater named for Fracastoro on the southern edge of Mare Nectaris.

Margherita Hack

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Franciscus Barocius

❯ **Barozzi, Francesco**

Franklin-Adams, John

Born **Peckham, (London), England, 5 August 1843**
Died **Enfield, (London), England, 13 August 1912**

John Franklin-Adams accomplished the first all-sky photographic atlas. A grand amateur in the Victorian tradition, Franklin-Adams received a general education at the Blackheath Proprietary School. Through additional schooling in Berlin and Harve, coupled with extensive travel on the Continent, he acquired gentlemanly refinement as well as a noted facility with languages. Franklin-Adams followed his father, John Adams, into a business career with the Lloyds insurance firm and rose to become one of its senior members.

Only in 1890 did Franklin-Adams begin to pursue astronomy as a serious hobby. In that year he resettled with his family in Wimbledon, and purchased a portable 4-in. refractor. He established his first permanent observatory at a vacation home in Argyllshire, Scotland, in about 1897, where a 6-in. equatorially mounted refractor replaced the smaller instrument. Having long been an amateur photographer, it was natural for Franklin-Adams to consider combining these two hobbies by photographing the night sky. With the encouragement of **David Gill**, Franklin-Adams commenced a photographic survey of the Milky Way in 1898, intending to create a mosaic map from multiple plates. H. Dennis Taylor of T. Cook & Sons had designed an optically fast 6-in. lens for a photographic telescope especially for the project. After hearing about Franklin-Adams's interest, in January 1900 **Edward Barnard** traveled to Argyllshire to meet Franklin-Adams and discuss the project. Barnard spent a month working with Franklin-Adams, during which time they made side-by-side comparisons of the Taylor lens with Barnard's famous Petzval lens. Barnard and Franklin-Adams then traveled to York for discussions with Taylor. At the conclusion of the visit, Taylor was commissioned to prepare a 10-in. aperture *f*/4 lens and to modify the 6-in. *f*/4.5 lens. Taylor gave Franklin-Adams the choice of the field size to which the 10-in. lens would be designed, offering to cover a field of 12° × 12° with good stellar images everywhere, or a 15° × 15° field with some deterioration of image quality in the corners of the plate. Franklin-Adams opted for the latter on the basis that such a plate would cover exactly 1 hour of right ascension at most declinations. By then he had expanded his project to encompass a survey of the entire sky visible from Argyllshire. With the larger field, fewer plates and exposures would be required to complete the project. The two cameras were mounted on a common polar axis in an English mounting of the type that is preferred for long-exposure photography. Franklin-Adams sought the advice of both **Jacobus Kapteyn** and **Cornelis Easton** in setting up his program of exposures for the atlas.

The photography of Northern Hemisphere skies was initiated in 1901. However, by 1902, Franklin-Adams's health had deteriorated severely. He was advised by his physician to seek treatment of his rheumatism in the hot springs at Caledon Sanitorium in Cape Province, South Africa. In June, 1903, Franklin-Adams sent the cameras and mounting ahead with his assistant, G. N. Kennedy, to extend his photographic charting to the Southern Hemisphere. Ever supportive, David Gill gave permission for him to set up his equipment on the grounds of the Royal Observatory, Cape of Good Hope. However, Gill also noted that while the mounting for the cameras was suitably stable, the wooden lens cells and tubes supporting the lenses and film holders were inadequate. Gill advised Franklin-Adams not to start the photography until he was convinced that the lens could be accurately centered and squared on with the film plates. In a haste to complete the work, and perhaps with his judgment partially impaired by his illness, Franklin-Adams elected to proceed with the photographic record of the Southern Hemisphere skies. The survey was completed before he left to return home.

Franklin-Adams returned to England in 1904, and established a new observatory at Mervel Hill near Godalming, Surrey. He constantly sought to improve his techniques and equipment including provision for more appropriate lens cells and tubes for the cameras. As the project to photograph the northern skies progressed over time, Franklin-Adams found that the plates taken at Mervel Hill were noticeably superior to his earlier photographic series. He planned another trip to South Africa in 1909, to repeat his survey of southern skies with the improved cameras, but his deteriorating physical condition prevented it. Instead, he presented the 10-in. telescope and other instruments to the Transvaal Observatory, Johannesburg. This institution (which was to become the Union Observatory, then the Republic Observatory) gainfully employed the Franklin-Adams telescope for decades thereafter, first to retake the southern sky survey plates for the Franklin-Adams atlas, and then for other survey work.

Franklin-Adams's Chart of the Heavens was published posthumously from 1912 to 1914 with financial assistance from the Royal Astronomical Society. The atlas consists of 206 charts, each covering a field 15° square at a scale of 15 mm per degree. It covers the entire sky as seen from Godalming, and Johannesburg. The charts show stars as faint as 17th magnitude. Completed sets of the Franklin-Adams charts were distributed as photographic prints to a limited number of observatories, and served as the basis for several catalogs.

Franklin-Adams participated in eclipse expeditions to Spain (1900) and Algeria (1905). He was a fellow of the Royal Astronomical Society. Minor planet (982) Franklina was named for him. He was married in 1879; the couple had five children.

Keith Snedegar

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Franks, William Sadler

Born **Newark, Nottinghamshire, England, 26 April 1851**
Died **East Grinstead, (West Sussex), England, 19 June 1935**

William Franks, a self-taught astronomer, dedicated his life to the estimation of star colors, and served as the professional assistant to several of the grand amateurs of the Victorian era. Franks's early life was spent in his father's business in Leicester. He soon showed an aptitude for science and mechanics, especially chemistry and electricity. However, a glance through a friend's telescope converted him to astronomy. Before long, Franks acquired an instrument of his own and housed it in a small homemade observatory.

After learning the rudiments of celestial observation, Franks settled down to a regular and systematic program of work. The visual estimate of star colors was an interest that persisted throughout his life, and he became very adept. His results, obtained with a small telescope, were found to be in good accord with those derived more recently by measurements of intensity distribution in photographic spectra. His first report, *A Catalogue of the Colours of 3890 Stars*, was communicated to the Royal Astronomical Society in 1878 by the Reverend **Thomas Webb** on his behalf. Eventually Franks contributed many papers on the subject to the *Monthly Notices* of the society, and was elected a fellow on 9 January 1880.

In other activities, Franks directed the Star-Colour Section of the Liverpool Astronomical Society (founded in 1881), and from 1890 to 1894 served as the first director of the Star-Colour Section of the newly formed British Astronomical Association. In 1892 he issued a report on the work of the previous 2 years, including an account of all the stars observed in the circumpolar and northern zones, consisting of 129 and 275 stars, respectively. These were part of a total of 940 stars scheduled for observation in four zones comprising 52 constellations. In 1921, at the instigation of Father **Johann Hagen**, Franks embarked on a revision of the color estimates of some 6,000 stars. His labors on star colors were published in a volume of the *Specola Vaticana* (1923).

In 1892, Franks joined **Isaac Roberts** at his Crowborough Observatory where he engaged in photographing nebulae and star clusters with the 20-in. reflector until the sudden death of his employer in 1904. Two years later, after assisting **Dorthea Klumpke Roberts** in organizing her late husband's records and closing the observatory, Franks went to live in Uxbridge, a suburb of London. During the next few years he worked at a number of small private observatories including Mervel Hill where he assisted **John Franklin-Adams** in the preparation of his star charts for publication. From 1910 until his death Franks was in charge of Frederick J. Hanbury's East Grinstead Observatory.

Franks contributed several papers of double-star measures to the *Monthly Notices of the Royal Astronomical Society* between 1914 and 1920. Even so he did less significant work than he had done with Roberts. In 1923 his work on star colors was given public recognition when the Council of the Royal Astronomical Society awarded him the Jackson-Gwilt Medal.

Franks's last publication, a paper on **Edward Barnard**'s Dark Nebulae, was published in the *Monthly Notices* in January 1930.

Richard Baum

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Franz, Julius Heinrich G.

Born **Rummels Burg (Miastko, Poland), 28 June 1847**
Died **Breslau (Wroclaw, Poland), 28 January 1913**

A German astronomer best known for his selenographic studies, Julius Heinrich G. Franz was the son of a physician. He studied mathematics and natural science in Halle and Berlin. By 1876 he was an observer at the Royal Observatory in Königsberg. His progress as an astronomer was apparently rapid, for in 1882 Franz was a leader of the official German expedition to observe the transit of Venus in Aiken, South Carolina, USA. In 1892 he became extraordinary professor, and in 1897 followed **Johann Galle** as director of the observatory in Breslau. Franz was a meticulous observer, and published many papers on measurements of comets, minor planets, and double stars.

Franz's first love, however, was the Moon. His first lunar researches involved the exact establishment of the location of the crater Möstig A, the Moon's fundamental point since the time of **Johann von Mädler**. The exact offset of this crater from the mean center of the visible lunar hemisphere is of great importance in measuring the positions of other craters. While still at Königsberg, Franz used **Friedrich Bessel**'s heliometer to accurately measure the positions of 150 points spread across the lunar surface. Calculations of the variations in apparent location of these points at different librations allowed him to accurately map the figure of the Moon. His small-scale topographical map showing elevated and depressed areas on the lunar surface was published in his treatise, *Die Figur des Mondes*, in 1899.

In 1906, after moving to Breslau, Franz published his popular book *Der Mond*. This small book is concise, yet detailed, and was very popular in the German-speaking world. Unfortunately, it was never translated into other languages.

Franz was a member of the committee established by the International Association of Academies to codify the lunar nomenclature. Under the auspices of this committee, he assumed responsibility for accurate mapping, at mean libration, of the outer portions of the Moon, a task that was completed and in press at the time of his death. The result, *Die Randlandschaften des Mondes*, was Franz's most important work. In it, he describes his measurement of features near the Moon's edge under favorable libration. These measurements were taken from glass plates supplied by the Lick and Paris observatories.

Though his name is little known today, Franz is an important figure in the history of selenography.

Leonard B. Abbey

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Fraunhofer, Joseph von

Born **Straubing, (Bavaria, Germany), 6 March 1787**
Died **Munich, (Germany), 7 June 1826**

Joseph Fraunhofer was in his day the leading producer of major telescope objectives, his testing of which led to his discovery of the Fraunhofer lines in the solar spectrum. He was the 11th and final child of the master glazier Franz Xaver Fraunhofer, whose own father Johann Michael had also been a master glassmaker in Straubing. The family of his mother, Maria Anna Frohlich, also included generations of glassmakers.

At age 11, Fraunhofer was left an orphan when both parents died within a year's time. He was sent to Munich as an apprentice to the court mirror maker and glasscutter Weichselberger, who restrained the ambitious boy from education outside the narrow confines of his training. On 21 July 1801, Weichselberger's house and workshop collapsed, but Fraunhofer survived. Prince Elector Maximilian Joseph IV of Bavaria (later King Maximilian I) took an interest in the fortunate boy, provided him a sum of money, and instructed his privy councilor Joseph von Utzschneider to ensure Fraunhofer's welfare.

Fraunhofer continued his apprenticeship with Weichselberger, but also trained with the optician Joseph Niggle on Sundays from 1801 to 1804. Though he became a journeyman of decorative glassmaking and cutting in 1804, he found his work dull and resented Weichselberger's discouragement of his efforts to master the theory and practice of optical glassmaking. Fraunhofer communicated his dissatisfaction to Utzschneider, now no longer privy councilor but still well connected; in 1806, he offered Fraunhofer a position in his Optical Institute in Munich.

Utzschneider saw to Fraunhofer's instruction in physics, optics, and mathematics, providing him with the appropriate textbooks on optics. After 8 months of apprenticeship in Munich, Fraunhofer was transferred to Utzschneider's glassmaking operation at a secularized Benedictine monastery in Benediktbeuern, in the foothills of the Bavarian Alps. There, Fraunhofer impressed everyone with his manual skills and application of his mathematical and optical studies. In 1807, Fraunhofer's essay on catoptrics (mirrors) showed that hyperbolic mirrors produced clearer images than parabolic mirrors in reflecting telescopes, and he invented a machine to cut segments of hyperbolic mirrors. He also invented a polishing machine that improved the spherical form of an objective lens produced by cutting.

In 1809, Utzschneider asked Fraunhofer to shift his attention from catoptrics to dioptrics in order to create achromatic lenses for telescopes and microscopes. Fraunhofer began training and collaborated with the glassmaker Pierre Louis Guinand, whom Utzschneider had brought from Switzerland to Munich in 1806 to produce high-quality achromatic lenses.

Fraunhofer's ascent at the Optical Institute was rapid. In September 1811, Utzschnieder appointed him as a director of optical-glass production at Benediktbeuern. By 1818, he would be director of all sections of the Optical Institute. Fraunhofer was now producing the finest optical glass in the world, and Bavaria was wresting from Britain leadership in that branch of technology.

When the Optical Institute returned to Munich from Benediktbeuern in 1819, Fraunhofer became active in the Bavarian Academy of Sciences. In 1823, he became director of the academy's Physics Museum and accepted the honorary title of Royal Bavarian Professor. These activities were in addition to his continuing responsibilities at the Optical Institute.

Fraunhofer never married. In the autumn of 1825, he contracted lung disease. Whether it was tuberculosis or a deterioration due to prolonged exposure to the furnace heat and lead oxide that affected many glassmakers remains unclear, but Fraunhofer died the following June.

Fraunhofer's work yielded the best refractors of the early to mid-19th century. Optical glass refracts colored light rays from an object and converges them to a focal point. There were two main varieties of optical quality glass suitable for powerful telescopes: "Flint glass" consisting of quartz, potassium carbonate, potassium nitrate, and lead oxide, and "crown glass" composed of silica from sand, calcium carbonate, and potassium carbonate. Elimination of chromatic aberrations required lens constructions by judicious combinations of varieties with complementary indices of refraction. But the slightest optical defect in a lens would hinder its value for making precision measurements. Aware of Guinand's techniques, Fraunhofer devised methods to produce large banks of homogeneous optical glass free of tiny bubbles and striae. Secrets of his manufacturing process that involved methods of applying heat and materials, stirring molten glass, timing of heating and cooling, and cutting and grinding lenses from the glass banks would die with him. Efforts by others such as Michael Faraday to duplicate Fraunhofer's achievement by "reverse engineering" – chemically analyzing his glass and attempting to duplicate its chemical constitution and hopefully its quality – failed miserably. Indeed, even his successors at the Optical Institute could not meet Fraunhofer's standard of optical quality following his death.

Though Fraunhofer would not reveal his methods of manufacture, he shared his procedure for calibrating lenses. This depended on careful determination of refractive and dispersive indices for all segments of the visible spectrum for each variety of optical glass. Previous efforts to measure the refraction of each color in the spectrum had been frustrated by the spectrum's apparent continuity, with no evident method to choose precisely which colors to measure. Around 1814, using the specific colors of light from sodium lamps to determine refractive indices for his glass, Fraunhofer compared these with effects of light from the Sun. He noted that the Sun's spectrum is crossed by nearly 600 dark lines, still known today as the Fraunhofer lines. In 1802, **William Wollaston** had first observed the most evident of these dark lines, but Fraunhofer was impressed by their presence throughout the visible spectrum. Convinced that the dark lines are an inherent property of solar light, he subsequently determined refractive indices over all segments of the spectrum with great accuracy by using the dark lines as positions of reference. Armed with the detailed knowledge of these indices, he could then shape lenses combining varieties of optical glass that minimized spherical and chromatic aberrations.

Though Fraunhofer's work is an essential chapter in the history of spectral analysis, he was primarily concerned with the dark lines as a means to calibrate his optical glass. He did not analyze the origin of these dark lines, an issue crucial to the later advent of spectroscopic analysis associated with **Gustav Kirchhoff** and **Robert Bunsen** (*circa* 1860) and the fruitful astronomical applications of spectroscopy that followed.

In the 1820s, inspired by Augustin Fresnel's model of light waves to account for interference phenomena, Fraunhofer carefully studied the effects of diffraction gratings. First using a grating of wires and subsequently constructing a grating by ruling up to 3,200 lines per Paris inch on a polished surface, he calculated accurate wavelengths for the prominent solar lines.

Fraunhofer's telescopes outfitted the leading observatories and provided the means for much important work done in the mid-19th century. **Friedrich Bessel** verified and measured long-sought stellar parallax (of the double-star 61 Cygni in 1838) using the Königsberg heliometer with a 6¼-in. objective crafted by Fraunhofer. Bessel's determination of the tiny parallax of 0.314 arc minute rested directly on the technical perfection of Fraunhofer's lenses. **Wilhelm Struve**'s contemporaneous measurement of the parallax of Vega was also done with a Fraunhofer refractor. In the early to mid-1800s, other notable astronomers including **Friedrich Struve** and **Wilhelm Olbers** discovered stars and carried out stellar measurements with unprecedented accuracy by using refracting telescopes manufactured according to their specifications at the Optical Institute.

Robert K. DeKosky

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Freundlich, Erwin

Born **Biebrich, (Hessen), Germany, 29 May 1885**
Died **Wiesbaden, Hessen, (Germany), 24 July 1964**

German, later refugee, astronomer Erwin Finlay Freundlich was among the very first exponents of the idea that astronomical observations could test theories of gravity beyond that of **Isaac Newton**, though his own efforts at providing observational confirmation for general relativity [GR] were generally unsuccessful. He was the son

of German manufacturer Friedrich Freundlich and a British mother, Ellen Finlayson, a version of whose surname he adopted during his 20 years at the University of Saint Andrews in Scotland. Following primary schooling in Biebrich and a classical education in nearby Wiesbaden, Freundlich worked briefly at a dockyard and began a course in naval architecture, which was brought to a quick end by a heart condition. He began work on mathematics, physics, and astronomy at Göttingen, receiving, with mathematician **Felix Klein**, a Ph.D. in 1910 for a thesis on analytic functions.

At Klein's urging, Freundlich applied for, and was appointed to, a position at the Royal Observatory in Berlin, working on positional astronomy, for which his mathematical background was good preparation. But he was already thinking of how astronomical circumstances might affect gravitation, and **Albert Einstein**, hearing of this, asked for his cooperation in making better measurements of the changing orbit of Mercury (eventually one of the classic tests of general relativity). Freundlich insisted on publishing the non-Newtonian result in 1913, over the objections of the observatory director. (He married Kate Kirschberg that same year.) In 1914, a member of the wealthy Krupp family of German industrialists financed an expedition for Freundlich to go to Crimea to witness the solar eclipse and look for the gravitational bending of light. This phenomenon was, by then, another of Einstein's predictions, though the full theory of general relativity was not ready for another year. The expedition was in Crimea when World War I broke out; Freundlich was briefly interned until he could be exchanged for a Russian prisoner of war held by the Germans.

In 1915, Freundlich published the suggestion that the gravitational redshift of light was responsible for the so called K term of **Edwin Frost** and **Walter Adams**, which is a net positive velocity for a population of stars that were supposed to be, on average, at rest relative to the Sun. He was at least half right: The gravitational redshift is about 3 km s^{-1}, compared with the 4.9 km s^{-1} they had reported, but Freundlich's suggestion was nevertheless unpopular in the astronomical community. In 1918, he resigned his Berlin position to work full time on solar observations in support of Einstein's ideas, at a facility generally called the Einstein Tower, financed by the Kaiser Wilhelm Institute. The primary goal was an accurate measurement of the gravitational redshift of the spectrum of sunlight. The effort never really succeeded because of the confounding effects of actual motions on the solar surface (*e. g.*, the Evershed effect), and the measurement is a marginal one even now. Freundlich's solar eclipse expeditions of 1922 and 1926 were clouded out, and the 1929 result from Sumatra was a deflection of light considerably and (Freundlich thought) significantly larger than the GR prediction. He spent a significant portion of the rest of his career trying to explain the difference as interesting new physics involving the interaction of gravitation and light. Subsequent measurements, particularly at radio wavelengths, have shown that the relativistic prediction is right and that Freundlich's (and some other) measurements had some systematic errors, probably resulting from the difference between hot daytime eclipse conditions and the nighttime comparison measurements.

Freundlich left Germany for Turkey in 1933, where he wrote what became the first astronomical textbook to be translated into Turkish, returned as professor of astronomy to the Charles University in 1937, but soon departed again to the Netherlands, where he was offered a position at the University of Saint Andrews. There he was to build an observatory and a department of astronomy. This Freundlich did, along with providing wartime instruction on celestial navigation to air ministry cadets. Realizing that the Saint Andrews facilities were not capable of serious research use, he oversaw the design and construction of the first Schmidt–Cassegrain telescope. This was so successful, especially for work on star clusters, that Freundlich commissioned a larger version. Meanwhile, he was among the first to apply the virial theorem to the motions of the stars in globular clusters and designed what he hoped would be an improvement on the **Albert Michelson** interferometer for measuring stellar diameters. Sadly, Freundlich wanted these to further his ideas on nonstandard interactions between gravity and light, and his reputation in the community gradually declined. He resigned the Napier professorship, to which he had been appointed in 1951, in 1959.

His successor at Saint Andrews, D. W. N. Stibbs, declined Finlay Freundlich's collaboration in the final commissioning of the 37-in. Schmidt–Cassegrain. The chief optician resigned, too, and the telescope was never entirely a success.

Finlay Freundlich retired to Wiesbaden, near his place of birth, and was honorary professor at the University of Mainz at the time of his death.

Helge Kragh

Alternate name

Finlay-Freundlich, Erwin

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Friedman, Herbert

Born **Brooklyn, New York, USA, 21 June 1916**
Died **Arlington, Virginia, USA, 9 September 2000**

Herbert Friedman pioneered X-ray astronomy using V-2 and Aerobee rockets during the late 1940s and 1950s. He and his team were the first to find X-ray emission from the Sun, discover the second X-ray source outside the Solar System – the Crab Nebula – and demonstrate that X-rays come from the nebula as a whole, not just from a central star as Friedman had hoped.

Friedman, the son of fine-arts dealer Samuel and Rebecca (*née* Seligson) Friedman, entered Brooklyn College as an art major. Under the influence of physicist Bernhard Kurrelmeyer, Friedman graduated in physics and spent the summer of 1936 looking for a job until Kurrelmeyer, a graduate of Johns Hopkins University, arranged for Friedman to be given a student instructorship there.

At Hopkins University, Friedman started laboratory work directly under Nobel Prize winner James Franck, the head of the physics department. When Franck left for Chicago, Friedman stayed at Hopkins University, working with the X-ray spectroscopist Joyce A. Bearden. Friedman used the fine structure of X-ray absorption edges to explore the structure of metals. Under Bearden's direction, Friedman built improved Geiger counters with thin entrance windows that increased the path length of soft X-rays through gas. Using Bearden's X-ray spectrometer with this improved detector, Friedman contributed to a better understanding of the nature of the transition metals, receiving a Ph.D. in 1940.

As a Jew, Friedman found a permanent position at a major university unattainable, though he evidently tried hard. He stayed on as an instructor at Hopkins University for a year, during which time Hopkins physicist **Alfred Pfund** helped him secure civil service employment at the Naval Research Laboratory [NRL]. The permanent job made it possible for Friedman to marry Gertrude Miller, an instructor at Brooklyn College.

At NRL, Friedman applied his knowledge of X-ray spectroscopy and gamma-ray radiography to diagnostic analysis of critical metals. He soon moved into the Optics Division under **Edward Hulburt** to create an entirely new electron optics branch. It was there that Friedman developed a fast and efficient technique for precisely cutting and tuning radio-frequency crystals, controlling the process by examining the Bragg reflections from the crystals. In 1945 he won the Navy's Distinguished Civilian Service Award for this work. Friedman applied improved X-ray-sensitive Geiger counters to the study of thin films and X-ray fluorescence analysis, developed reliable gamma-ray Geiger counters for radiation exposure surveys of Hiroshima and Nagasaki, and participated in setting up the radiation-monitoring systems that detected Soviet nuclear tests in 1949.

Hulburt drew Friedman into his group that was performing ultraviolet solar and atmospheric studies with captured German V-2 rockets at White Sands, New Mexico. By the end of the decade, they had still not solved major scientific problems regarding the high-energy spectrum of the Sun and the source of ionizing radiation in the Earth's upper atmosphere. Applying his electronic detector expertise, Friedman started flying banks of counters on V-2 rockets in 1949 and soon provided a more detailed understanding of how the solar ultraviolet and X-ray spectrum influenced different layers in the Earth's high atmosphere. Friedman's electronic detectors also solved the data retrieval problem because the information could be transmitted by radio during flight and did not require physical retrieval. This new application of his expertise appealed to Friedman; he concentrated on space science for the rest of his career.

During the 1950s, Friedman's group continued solar and atmospheric research. A 1952 flight on the Navy's Viking rocket using counters sensitive to extreme ultraviolet and X-ray confirmed Friedman's model of the solar source of ionization in the E layer. After that flight, Friedman relied heavily on a cheaper balloon-launched rocket system called a "Rockoon" and coordinated a series of shipboard rocket launches to study solar X-rays from widely differing parts of the Earth. More than anyone else, Friedman developed the instrumentation expertise that would prove to be important in the Sputnik era. The work of his core staff, men like E. T. Byram, Talbot Chubb, and Robert Kreplin, set the stage for scientific research with sounding rockets and satellites in the 1960s. In addition to devising counters that worked reliably and honestly in a very hostile environment, they devised a simple way to produce an X-ray image of the Sun using a pinhole camera, developed a rugged Bragg crystal spectrometer for measuring hard X-rays, and eventually provided the detectors for the Navy's SOLRAD satellites dedicated to long-term monitoring of the high-energy radiation from the Sun.

From the mid-1950s Friedman's group developed larger detector systems and small telescopic devices intended to detect nonsolar astronomical X-ray sources. After some initially confusing results, which created a schism in the group, they decided that they had evidence of emission from diffuse sources within the Milky Way. But in 1962, Riccardo Giacconi's team from American Science and Engineering – see **Bruno Rossi** – became the first to unambiguously detect a nonsolar X-ray point source in the region of Scorpius. NRL rocket flights in 1963 improved the measured position of Sco X-1, confirmed the existence of an X-ray backround, and found the second compact source at the position of the 1054 supernova remnant (Crab Nebula). Friedman hoped that this might be the glow of a cooling neutron star left behind by the explosion, as had been suggested in 1933/1934 by **Walter Baade** and **Fritz Zwicky**. Friedman's group knew that the limb of the Moon would pass directly across the nebula in 1964. They managed to time a flight so that the 5 min of flight data acquisition covered precisely the 5 min when the Moon was moving across the nebula. They expected the source to disappear suddenly, when the neutron star was occulted. Instead, it faded gradually, meaning that the source was the extended body of the nebula, not the neutron star. The X-ray radiation from a 1,000-year-old remnant required continuous energy input, accounted for by the discovery of a neutron star (pulsar) in the Nebula 4 years later.

In 1958, Friedman was made superintendent of a new atmospheric and astrophysics division at NRL. After reorganization in 1963, he became superintendent of the Space Science Division and Chief Scientist in the E. O. Hulburt Center for Space Research, positions he held until 1980.

Friedman's staff won an important role in the High Energy Astrophysical Observatory [HEAO] satellite series created by the National Aeronautics and Space Administration [NASA]. Encouraged by NASA, he conceptualized using leftover Apollo hardware to create a large man-tended X-ray telescope in orbit that eventually evolved to the unmanned HEAO concept. Friedman designed a huge bank of seven tray-like thin window X-ray proportional counters that were intended to produce a sensitive map of the X-ray sky that included spectrum, intensity, and time variations. Launched on HEAO A-1 in August 1977, the Large Area Sky Survey Experiment observed until January 1979 and cataloged a wealth of data on particular sources and source classes that supported further studies of X-ray emission from clusters of galaxies. Evidence for a continuous X-ray background was also strengthened.

By the mid-1970s Friedman was writing popular books on astronomy that have received wide appreciation. He also acted as a spokesperson and arbitrator for science and science policy in Washington. Friedman was honored with a long list of awards and prizes including honorary doctorates (Tübingen and Michigan); election to the National Academy of Sciences; and medals from the Royal Society (London), Royal Astronomical Society, and others. He was a National Medal of Science recipient in 1968 and won the Wolf Foundation Prize in Physics (1987). Richard Nixon appointed Friedman to the President's Science Advisory Committee [PSAC]. Friedman also advised the Atomic Energy Commission and was a member of the Space Science Board of the National Academy of Science.

Herb and Gertrude Friedman raised two sons, Paul and Jon. He died of cancer at his home.

David DeVorkin

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Friedmann, Alexander Alexandrovich

Born **Saint Petersburg, Russia, 4/16 June 1888**
Died **Leningrad (Saint Petersburg, Russia), 16 September 1925**

Alexander Friedmann was a mathematician and cosmologist who first proposed the idea of a "Big Bang" Universe. His father, also Alexander Alexandrovich Friedmann, was a dancer and composer of ballet music; his mother, Ludmila Ignatievna Voyachek, was a pianist and music teacher. In 1906, Friedmann entered the University of Saint Petersburg where he studied mathematics with Vladimir Andreyevich Steklov and theoretical physics with Pavel Sigizmundovich Ehrenfest. In 1911, he married Ekaterina Petrovna Dorofeyeva, a well-educated woman who was very devoted to him and offered her assistance by translating articles, reading proofs, and so forth. Yet, Friedmann divorced her after falling in love with Natalia Yevgenievna Malinina, a geophysicist, whom he married in 1923.

In 1913, after a series of examinations, Friedmann became a candidate for a master's degree in pure and applied mathematics. That year, he obtained a position in the Aerological Observatory in Pavlovsk, a branch of the Main Physical (later Geophysical) Observatory of the Russian Academy of Sciences. During World War I, Friedmann served as a meteorologist and even learned to fly his own observational airplane. In 1917, he was put in charge of the aviation instruments plant, Aviapribor, in Moscow. But the following year, he joined the Department of Mechanics of the new Perm branch of Petrograd University. In 1920, Friedmann returned to the Main Geophysical Observatory in Petrograd, as senior physicist in charge of the mathematical bureau. His dissertation, "The Hydromechanics of a Compressible Fluid," was completed in 1922 and later published.

While in Petrograd, Friedmann began a study of **Albert Einstein**'s general theory of relativity. With Vsevelod Konstantinovich Frederiks, he undertook the writing of a textbook on the subject, of which only the first part, on tensor calculus, was ever completed (1924). Friedmann's fundamental contributions to relativistic cosmology are contained in two papers, "On the Curvature of Space," and "On the Possibility of a World with Constant Negative Curvature," that were published in the *Zeitschrift für Physik* (1922, 1924). Friedmann's notion of an expanding universe was at first rejected by Einstein, who asserted without proof that his conclusion rested upon a mathematical error. Einstein later withdrew this statement in another brief notice. Evidence supporting Friedmann's model of the expanding universe was later supplied by **Edwin Hubble**'s announcement of the velocity–distance relationship, although the mathematician did not live to see his ideas vindicated. Friedmann also published a semipopular book, *The World as Space and Time* (1923).

In 1925, Friedmann became director of the Main Geophysical Observatory, which was charged since 1921 with the meteorological service of the Russian Republic. On 17 July 1925, he mounted a meteorological balloon with Pavel Fyodorovich Fedoseyenko and climbed to 7,400 m altitude, thus breaking the former Russian record of 6,400 m for balloon flights. However, Friedmann fell ill with typhoid fever and died in the Pervukhin Hospital. His death prevented him from completing his scientific report on the balloon ascent.

Roberto Torretti

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Frisi, Paolo

Born **Milan, (Italy), 13 April 1728**
Died **Milan, (Italy), 22 November 1784**

Paolo Frisi was a mathematician, philosopher, and astronomer concerned with applications of Newtonian theory. A Barnabite monk from about 1746, he was professor of philosophy at Casale Novara and Collegio Alessandro in Milan (1753–1756) and professor of philosophy at Pisa (1756–1764). His final post was professor of mathematics at the Scuola Palatina in Milan from 1764.

Frisi's physics researches included hydraulics, electricity, and light, and his mathematical work concentrated upon kinematics. In astronomy, he contributed a book on the movement of the Earth (*De motu diurno terrae*), which won a prize from the Berlin Academy. He also published work on the obliquity of the ecliptic and the determination of the arc of the meridian. Frisi's *Cosmografia* of 1785 was a thoroughly modern text. He also contributed to the history of science through his studies of **Galileo Galilei**, **Isaac Newton**, **Bonaventura Cavalieri**, and **Jean d'Alembert**.

Frisi was a conduit of the latest French ideas into Milanese society. His work was honored by membership in the academies of Paris, London, Berlin and Saint Petersburg.

Richard A. Jarrell

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Frisius, Gemma Reinerus

Born **Dokkum, (Friesland, the Netherlands), 8 December 1508**
Died **Louvain, (Belgium), 25 May 1555**

Gemma Frisius is mostly remembered as a mathematician, astronomer, cosmographer, and producer of globes.

Until 1514 at least, Frisius lived in Dokkum. Following his parents' sudden death, he went to Groningen, where relatives took care of his education and schooling. Probably in the autumn of 1525, Frisius was sent to Louvain for higher studies. He entered the *Lily* and probably also took courses at the *Collegium Trilingue*. On 26 February 1526, Frisius matriculated at the Faculty of Arts, and 2 years later he was promoted to *magister artium*. In the years following this promotion, Frisius became known as the successful author of a series of cosmographical, astronomical, and mathematical treatises. For some time, he even worked exclusively as a mathematician. On 2 June 1534 he married Barbara, and in 1535 a son, **Cornelius Gemma**, was born.

Frisius became a member of the University Council in 1535. He entered the Faculty of Medicine before 1 August 1536 and in 1541 was promoted to doctor of medicine, but he had already been given a public chair in medicine at Louvain University from 1537 onwards. In his occupation as a physician he provided medical treatment to a noble and wealthy clientele including Emperor Charles V. Frisius was never assigned a public chair of mathematics, but he gave private tuition in mathematics at his home. By April 1543 he had started a private course of mathematics primarily concerned with geometry and astronomy. In his *De Astrolabo*, Frisius also refers to private lessons on the use of astronomical instruments such as the *parallellogrammic planisphaerium*. **Gerhard Kremer** mentions courses on the *theorica planetarum*. He continued teaching mathematics until at least the year 1547.

Frisius enjoyed the support of the Court of Charles V. He was often consulted by the emperor, not only in his capacity as a physician, but also as an astronomer. The story goes that the emperor once pointed out a mistake on Frisius's 1540 map of the world, whereupon the mapmaker dedicated the map to him. Frisius could also rely on Johannes Dantiscus, who as ambassador of the Polish King Sigismond I resided at the court of Charles V from early 1531 until March 1532. Dantiscus became acquainted with Frisius, and when Dantiscus left Louvain in March 1532 and returned to Culm, he invited Frisius to come to Poland with him to meet **Nicolaus Copernicus**. However, for several reasons, Frisius never left for Poland.

Frisius's body of writings consists of a manuscript and a published part. The first part encompasses his letters to Dantiscus and his annotations in his copy of Copernicus' *De Revolutionibus*. Several years before *De Revolutionibus* was published, Frisius knew about Copernicus' theory, as Dantiscus had informed him about it during his stay in the Low Countries in 1531/1532. The Copernicus copy with Frisius's annotations is preserved at the Provinciale Bibliotheek in Leeuwarden, Friesland, and is the most extensively annotated copy of the 16th century. Frisius's interpretation of the heliocentric theory was not merely instrumentalist but realist as well, as is also shown by his posthumously published preface to **Johann Stabius**' *Ephemerides*. Here Frisius explained that he preferred Copernicus' new theory not only because it offered more accurate predictions and showed a better agreement with the observations, but also because it explained the phenomena, whereas **Ptolemy**'s hypotheses could merely save them.

Among Frisius's published writings we find his reedition of **Peter Apian**'s *Cosmographia* (Landshut, 1524), published in February 1529. In the editions of 1533, 1540, 1545, and 1548, Frisius made many significant additions to Apianus' text. (For example, the *addendum* to Apianus' chapter *De Ventis* discussed the problems of navigation and magnetical declination.) Until the end of the 16th century, the *Cosmographia* was considered to be a standard handbook of descriptive and practical geography and astronomy, and it went through numerous editions, reprints, and translations.

De Principiis Astronomiae et Cosmographiae, Deque usu globi ab eodem editi. Item de Orbis divisione, & Insulis, rebusque nuper inventis (1530) was conceived as a commentary on a globe, and special attention was given to the simplification of astronomical observations and calculations, rather than to direct practical applications. The book consists of three parts dealing with, respectively, the principles of astronomy and cosmography (*De principiis cosmographiae*), the use of globes (*De usu globi*), and a descriptive geography of the Earth (*De orbis divisione*). The *De Principiis* also contains the first of Frisius's two most important discoveries, the determination of longitudes by means of the time difference between two different places. The *Libellus de locorum describendorum ratione et de eorum distantiis inveniendis* (1533) served as a manual for topographical triangulation. Frisius explained how to establish the position of a place (longitude and latitude) in relation to other places and draw local maps by the means of trigonometry, following a method first developed by Jacob of Deventer in 1536.

In *Usus annuli astronomici* (1539), Frisius described the improvements he made to an instrument composed of a small portable equinoctial armillary sphere with three rings. He reduced the instrument to pocket size, the *annulus astronomicus*, popular until well into the 18th century, with movable rings for the horizon, Equator, and ecliptic.

In *De Radio astronomico* (1545), Frisius showed that he had already thoroughly read Copernicus' *De Revolutionibus* (1543). He clearly preferred the Copernican tables and his representation of the lunar motion, compared with Ptolemy's, and he severely criticized the theory of homocentric spheres of **Eudoxus**, which **Girolamo Fracastoro** had tried to reintroduce in the 1530s.

The posthumous *De Astrolabo catholico* (1556) was conceived as a manual of the astrolabe that could be used at every latitude. It often repeated Frisius's preference for the Copernican parameters, and had a large section on astrology as well.

Fernand Hallyn and *Cindy Lammens*

Alternate name

Regnerus

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Fromondus, Libertus

Born **1587**
Died **1653**

Trying to reconcile **Galileo Galilei**'s telescopic observations with classical thought, Libertus Fromondus of Louvain championed the idea that the Milky Way is a ring of faint stars located between the "sphere" of Saturn and the more distant firmament. In a work on the comet C/1618 W1 he still invoked the Milky Way as a birthplace of comets.

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Frost, Edwin Brant

Born **Brattleboro, Vermont, USA, 14 July 1866**
Died **Chicago, Illinois, USA, 14 May 1935**

Edwin Frost, astronomical spectroscopist and administrator, served as the director of the Yerkes Observatory during the years following the departure of its founder, **George Hale**. He would guide the observatory for almost three decades, through a difficult transitional period between the early days of optimism and the brilliance that characterized Hale's directorship and the observatory's resurgence as a scientific research institution under **Otto Struve**.

The son of physician and Dartmouth college professor of medicine Carl Pennington Frost, and Elizabeth Ann (*née* DuBois), Frost was an eighth-generation American; the family's history dated back to an ancestor who arrived in Boston in 1635. He received a splendid education. He graduated from Dartmouth College (with honors) in physics, giving a senior oration on the great nova (now known to have been a supernova) in the Andromeda Nebula in 1885 (SN 1885 A). Frost then completed some graduate work in chemistry at Dartmouth and studied briefly under the outstanding solar astrophysicist **Charles Young** at Princeton University. Next he studied abroad as did many aspiring American astronomers and astrophysicists at the time. In the early 1890s, he attended classes in Strasbourg University and studied astrophysics under **Hermann Vogel** and **Julius Scheiner** at the great Astrophysical Observatory in Potsdam. But it was the discovery of Nova Aurigae at the Lick Observatory in 1893, which, as Frost later recalled, solidified his resolve to study astronomical spectroscopy.

From 1892 to 1898, Frost taught at Dartmouth College, where he married Mary E. Hazard; they had three children. During his tenure at Dartmouth, Frost completed translation, revision, and major updating of Scheiner's text on stellar spectroscopy, published in 1898 as *A Treatise on Astronomical Spectroscopy*. In **James Keeler**'s view, *Astronomical Spectroscopy* was "admirably adapted to the requirements of the specialist …"

In 1898, Hale hired Frost as professor of astrophysics for the University of Chicago's new Yerkes Observatory, at Williams Bay, Wisconsin. Hale wrote to Catherine Bruce, the source of funds for the position, that "next to professor Keeler … professor Frost [was] better qualified than anyone else we could secure for the place." Frost continued to spend winters, when observing in the unheated Yerkes dome was often unpleasant, teaching the astronomy course at Dartmouth.

At Yerkes Observatory, Frost was assigned to measure radial velocities of stars with a spectrograph attached to the 40-in. refractor. He shared that spectrograph with Hale, who was studying carbon stars. To accommodate both observing programs, the spectrograph's prisms, lenses, and cameras had to be changed constantly. That was all but fatal to precise measurements, which demand a stable equipment configuration. Frost's program suffered in comparison with **William Campbell**'s radial-velocity program at the Lick Observatory, since not only did Campbell possess a drive to do research, which Frost lacked, but his spectrograph was designed for and exclusively dedicated to measuring stellar radial velocities. In addition, the climate at Lick Observatory was superior to that of Williams Bay for astronomical research. As a result, Frost's initial productivity was less than Campbell's.

After deciding he had had enough of trying to do astrophysics research in Wisconsin and attracted by the climate and superior observing conditions on Mount Wilson Observatory in southern California, Hale left Yerkes in 1903. He also managed to lure many of the leading members of the Yerkes staff, including **George Ritchey**, **Walter Adams**, and **Ferdinand Ellerman** to Mount Wilson Observatory with him. Frost was appointed to succeed Hale as director of the Yerkes Observatory. Frost did not have very favorable circumstances, and in the following decade was forced to confront a number of problems that Hale left behind. Frost assumed Hale's responsibilities as Managing Editor of the *Astrophysical Journal*, and although Hale remained on the masthead as General Editor for a number of years, the administrative and, increasingly, the technical burdens of sustaining that important journal fell on Frost's shoulders. Furthermore, the staff that remained at Yerkes Observatory reflected the mass departure of both youth and talent with Hale, and the university placed salaries of the staff in jeopardy. **Philip Fox** remained at Yerkes Observatory only 6 years before he accepted the directorship of the Dearborn Observatory. Frost's efforts to replace them met with little success. Although he recruited diligently, there were not enough qualified astronomers available to fill the more attractive positions at Mount Wilson, Lick, and other observatories, which enjoyed superior facilities and climates, much less the marginal posts at Yerkes Observatory. Thus, Frost was forced to temporize in staffing decisions. In 1915 he took the unusual steps of recruiting a relatively untried **George Van Biesbroeck**, a civil-engineer-turned-astronomer from Belgium, and allowing amateur astronomer **John Mellish** to work as an unpaid observer, both on a trial basis. Van Biesbroeck spent over 48 years at Yerkes Observatory, but Mellish was unable to attain a permanent position on the staff.

Frost had considerably more success in recruiting and training graduate students as part of Yerkes' role as a teaching institution. The list of Ph.D.s graduated from Yerkes University/University of Chicago during Frost's tenure included **Nicholas Bobrovnikoff**, **Curvin Gingrich**, **Edwin Hubble**, **Philip Keenan**, Oliver J. Lee, **Otto Struve**, and **William Morgan**. All except Struve and Morgan left Yerkes Observatory for greener pastures based on research potential or teaching opportunities. Frost continued to struggle with the radial-velocity program, but despite his magnificent education and many superb qualities as a humane and well-rounded person, Frost proved to be a lackluster director of research. Under his directorship, research productivity at the Yerkes Observatory went into a long period of decline.

Also, Frost's personal difficulties, which might have broken a lesser man, were mounting. In December 1915, while observing with the 40-in. refractor, he suffered a retinal tear in his right eye that within a year led to the total loss of vision in that eye. His left eye was affected by a cataract, and several years later it too suffered from a hemorrhage. Thereafter, Frost was unable to read, or even, for all ordinary purposes, to see. Being blind was, for a research astronomer, an overwhelming handicap. Frost tried to adapt to his blindness as best he could. He had staff members, especially observatory librarian Storrs B. Barrett, keep him up to date by reading articles from research journals. Frost lectured widely, and continued to edit the *Astrophysical Journal*, which he did for 30 years, a longer period of time than any other editor. He also had a sign affixed to the door of his office informing his staff to make sure it remained open at all times, to prevent him from bumping into it.

In 1926, comparatively late in Frost's career as director at Yerkes, the University of Texas asked the directors of great observatories for advice on the use of the William Johnson McDonald legacy that was to be devoted to construction of an astronomical observatory. Frost's detailed and lengthy response strengthened the university's resolve to continue the estate litigation in which they were ultimately successful. As they turned to application of the conditions of the McDonald will in 1929, they naturally returned to Frost for advice. Struve, who replaced Frost, guided the University of Chicago into an agreement that led to the construction and operation of the McDonald Observatory as a joint venture between the two universities.

Frost hung on to the Yerkes directorship until 1932, when he reached 65, the usual retirement age. He and his wife moved into a new home, Brantwood, west of the observatory. Always a nature lover, Frost tended a garden of roses, and even developed his own variety of yellow single-petal roses, the "Frost rose," which still blooms in Williams Bay. A heavy wire strung waist-high from tree to tree from the house to the observatory guided Frost, in his blindness, on short walks. "Those who knew him in the years of his blindness will forever retain … a vision of the superb courage with which he faced his affliction," Struve later wrote. "Never did he complain or show annoyance."

William Sheehan

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Fu An

Flourished **China, 1st century CE**

Nothing is known of Chinese astronomer Fu An's life, but his astronomical work was recorded in the *Hou Han shu* (History of the later Han dynasty) by Fan Ye (398–446).

Before the time of Fu An, the Chinese usually would use a simple device to observe the relative locations of celestial bodies. The device was made up of a polar axis, a fixed meridian ring, a fixed equatorial ring, and a binary ring moveable around the polar axis. The binary ring consisted of two same-sized rings. Between the two rings was a sighting tube across their diameter. The tube could be moved both around the polar axis and along the circumference of the binary ring. Fu An's contribution to this astronomical instrument was to add a fixed ecliptic ring with graduations on it so that the approximate ecliptic longitudes of celestial bodies could be obtained. It should be pointed out that Fu An's device was not an ecliptic mounting but an equatorial mounting. Although he designed an ecliptic ring for his instrument, he did not use the ecliptic coordinate system.

Fu An's design was highly praised by **Jia Kui**, an astronomer of the same period who recommended Fu's design to the Han Emperor. The device's construction was approved and it was installed in the imperial observatory.

Li Di

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Furness, Caroline Ellen

Born **Cleveland, Ohio, USA, 24 June 1869**
Died **New York, New York, USA, 9 February 1936**

Carolyn Furness educated many women astronomers during her tenure as the Vassar College Professor of Astronomy and the director of the Vassar College Observatory. Her valuable monograph on variable star astronomy served as a detailed introduction to the field for several generations of graduate astrophysics students as well as for large numbers of amateur astronomers.

As the daughter of high-school science teacher Henry Benjamin Furness and Caroline Sara (*née* Baker) Furness, Caroline Ellen Furness had a privileged childhood that sustained her early scientific interests. However, it was over the objections of her widowed father and sister that Furness entered the astronomy program as an undergraduate during the last year of **Maria Mitchell**'s long tenure at Vassar College. Her primary instructor in astronomy at Vassar was Mary Watson Whitney (1847–1941). Whitney had been one of Mitchell's star pupils; thus, Furness can be considered an indirect academic descendent of Mitchell among women in astronomy. After graduating from Vassar in 1891, Furness taught in high schools in Connecticut and Ohio before she was called back to Vassar to assist Whitney with the astronomy program in 1894. The astronomy program at Vassar had grown to 160 students in eight courses, and Whitney could no longer carry the load by herself. From her personal funds, Whitney hired Furness to assist with this teaching and observatory load from 1894 until 1898. By then, Furness was convinced that she wanted a formal position in which she could teach and do research at the college level. Whitney encouraged Furness to enter the graduate astronomy program at Columbia University.

Furness benefited greatly in her graduate classes at Columbia University from the rigorous training she received from Whitney at Vassar. Her graduate advisor was Harold Jacoby (1865–1912). After successfully defending her thesis, *A Catalogue of Stars within One*

Degree of the North Pole, and Optical Distortion of the Helsingfors Astro-photographic Telescope, Deduced from Photographic Measures, in 1900, Furness earned the first Ph.D. in astronomy granted to a woman by Columbia University. Furness returned to Vassar to assist Whitney with her heavy teaching load when she was not conducting her own research. In 1903, Vassar formalized Furness's role by appointing her to the faculty as an instructor, and by 1911 she had become an associate professor and acting director of the observatory.

When Whitney retired, Furness assumed full responsibility for astronomy at Vassar in 1913, having a well-established program in place. Nevertheless, Furness expanded the program through the addition of graduate courses that kept pace with research developments in astronomy and astrophysics. The Vassar program was a popular one because its graduates were always well trained and were in demand as computers for the burgeoning staffs at professional observatories. In 1915, Furness was appointed Maria Mitchell Professor of Astronomy and Director of the Vassar College Observatory.

Although her work included traditional observational astronomy related to comets and asteroids, Furness is perhaps best known for her advancement of the cause of variable star astronomy. Furness's monographic book on variable stars, published in 1915, established her as the authority in this field and was a standard reference work for several generations of astronomers. She first acquired a taste for variable stars from Whitney during her undergraduate days at Vassar. Furness joined the small corps of volunteer variable star observers organized by **Edward Pickering** at Harvard College Observatory, and recruited other women for this work. When **William Olcott** founded the American Association of Variable Star Observers (AAVSO) in 1911, Furness was a charter member. She encouraged the interest of her students in variable stars by taking them to AAVSO meetings and sponsoring their presentation of occasional technical papers in those meetings. She was an active member of the association and for a number of years supported the work of the AAVSO Occultation Committee by assisting with the tedious mathematical reduction of predictions and observations.

Furness was elected a Fellow of the Royal Astronomical Society in 1922. Well known and respected in the astronomical community, Furness served on many advisory boards, for example the committee that guided the foundation of the Hayden Planetarium and the advisory committee of the New York Amateur Astronomers Association established there shortly after the planetarium opened.

Thomas R. Williams

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Fusoris, Jean [Johanne]

Born **Giraumont, (Meurthe-et-Moselle), France, *circa* 1365**
Died ***circa* 1436**

Jean Fusoris is best known for his astrolabes, of which at least 13 survive, and for a treatise on the astrolabe. His design innovations became standard in the construction of these instruments.

Fusoris was born the son of a pewterer. He studied arts and medicine, attaining the bachelor's degree in 1379. After learning his father's craft, he returned for his master's degree, which he obtained in 1391. Fusoris then served as one of the master's regents in Paris until 1400. He established a school and opened an instrument workshop in Paris making astrolabes, clocks, and other instruments. Fusoris continued to study theology and accumulated various canonries.

Fusoris was elected a member of the French embassy in England in 1415, where he met Richard of Courteny, Bishop of Norwich. Norwich bought an astrolabe from Fusoris but did not pay for it. When Fusoris returned to England in an attempt to collect the debt, war had broken out between France and England, and he was arrested as a suspected spy. He was exiled to Mézières-sur-Meuze and later to Reims, but continued to accept and fill commissions for instruments while in exile. In addition to his instruments, Fusoris wrote a treatise on the astrolabe, in which he detailed the improvements he incorporated into his instruments, and other tracts on mathematics and astronomy.

Fusoris was one of the first philosopher-churchmen to set up a commercial workshop to produce instruments. His workshop represented several turning points in the history of instrument manufacture in general and in the history of the astrolabe in particular. It was unique at the time for a person of his prestige and position to establish a commercial enterprise. Prior to this time, nameless guild craftsmen or others produced most astrolabes. It cannot be said that Fusoris started a revolution in the instrument industry, but his shop certainly anticipated later ateliers headed by prominent scholars. His influence on the astrolabe cannot be overstated. He was the first to integrate all of the astrolabe elements into a uniquely European instrument, and the design elements of Fusoris' astrolabes became virtually universal. Among his innovations were dividing the limb by equal hours, the use of a rule (ostensor) on the front of the instrument, and improvements in the design of the alidade. His elegant and artistic design of astrolabe components was a milestone compared with the bulky and awkward instruments that preceded his.

James Morrison

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G

Gaillot, Jean-Baptiste-Aimable

Born **Saint-Jean-sur-Tourbe, Marne, France, 27 April 1834**
Died **Chartres, Eure-et-Loire, France, 4 June 1921**

Aimable Gaillot specialized in celestial mechanics and eliminated notable residuals in the orbits of the jovian planets; his values for the masses of these planets were the most accurate ones then available. His parents were Jean Baptiste Gaillot and Marie Catherine Gillet.

Gaillot was recruited in 1861 by **Urbain Le Verrier**, director of the Paris Observatory. His career was spent entirely in the Service des calculs (Bureau of computation), of which he became the head in 1873. Gaillot remained devoted to Le Verrier, even after the latter's forced resignation (1870). In this way, he was able to complete the revision of Le Verrier's planetary theories and was active in several geodetic campaigns.

Gaillot was appointed *astronome adjoint* in 1868 and *astronome titulaire* in 1874. When **Moritz Löewy** was chosen as the new director of the Paris Observatory, he called upon Gaillot to be his deputy director, a position Gaillot held until his retirement in 1903.

Another of Gaillot's important contributions was his compilation of nearly 400,000 meridian observations of stars (gathered between 1837 and 1881) into the eight-volume *Catalogue de l'Observatoire de Paris* (1887). He also served as editor of numerous volumes of the *Annales de l'Observatoire de Paris*, founded by Le Verrier.

Gaillot, however, was chiefly engaged in the refinement of the orbits of the planets. These were successively introduced into the *Connaissance des temps* (the French nautical almanac) after 1864. Originally, the orbits of Jupiter, Saturn, Uranus, and Neptune displayed residuals on the order of 10 arc-seconds. By a laborious procedure, Gaillot successively derived new orbital elements and masses for these planets, whose final results differed by at most a few arc seconds. For example, Gaillot reduced the discrepancies in Saturn's mass from one part in a hundred to one part in a thousand, as compared with modern values. Gaillot completed this work in 1913 when he was almost 80 years old.

Solange Grillot

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Galilei, Galileo

Born **Pisa, (Italy), 15 February 1564**
Died **Arcetri near Florence, (Italy), 8 January 1642**

Although Galileo Galilei (universally known by his first name) is best remembered in the history of astronomy for his telescopic discoveries, his greatest contribution was his approach to physics, which led to the work of **Christiaan Huygens** and **Isaac Newton**. Galilei's father Vincenzio was a musician who made significant contributions to musicology and influenced the son's experimental approach. In 1581, Galilei enrolled at the University of Pisa to study medicine, but soon switched to mathematics, which he also studied privately. In 1585, he left the university without a degree, turning to private teaching and research. In 1589 he became professor of mathematics at the University of Pisa, and then from 1592 to 1610 at the University of Padua.

During this period, Galilei research focused primarily on the nature of motion. He was critical of Aristotelian physics, favorably inclined toward Archimedean statics and mathematics, and innovatively experimental, in so far as he pioneered the procedure of combining empirical observation with quantitative mathematization and conceptual theorizing. Following this approach, he formulated, justified, and to some extent systematized various mechanical principles: an approximation to the law of inertia, the composition of motion, the laws that in free fall the distance fallen increases as the square of the time elapsed and that the velocity acquired is directly proportional to the time, the isochronism of the pendulum, and the parabolic path of projectiles. However, he did not publish any of these results during that period, indeed not publishing a systematic account of them until the *Two New Sciences* (Leiden, 1638).

The main reason for this delay was that in 1609 Galilei became actively involved in astronomy. He was already acquainted with **Nicolaus Copernicus**'s theory of a moving Earth and appreciative of the fact that Copernicus had advanced a novel argument. Galileo also had intuited that the geokinetic theory was more consistent in general with the new physics than was the geostatic theory. In particular, he had been attracted to Copernicanism because he felt that the Earth's motion could best explain why the tides occur. But he had not published or articulated this general intuition and this particular feeling. Moreover, Galilei was acutely aware of the considerable evidence against Copernicanism: The Earth's motion seemed epistemologically absurd because it contradicted direct sense experience; astronomically false because it had consequences that could not be observed (such as the similarity between terrestrial and heavenly bodies, Venus's phases, and annual stellar parallax); mechanically impossible because the available laws of motion implied that bodies on a rotating Earth would, for example, follow a slanted rather than vertical path in free fall, and would be thrown off by centrifugal force; and theologically heretical because it contradicted the words and the traditional interpretations of Scripture. Until 1609, Galilei judged that the anti-Copernican arguments far outweighed the pro-Copernican ones.

However, the telescopic discoveries led Galilei to a major reassessment. In 1609, he perfected the telescope to such an extent as to make it an astronomically useful instrument that could not be duplicated by others for some time. By this means, he made several startling discoveries that he immediately published in *The Sidereal Messenger* (Venice, 1610): that the Moon's surface is full of mountains and valleys, that innumerable other stars exist besides those visible to the naked eye, that the Milky Way and the nebulas are dense collections of large numbers of individual stars, and that the planet Jupiter has four satellites revolving around it at different distances and with different periods. As a result, Galilei became a celebrity. Resigning his professorship at Padua, he was appointed philosopher and chief mathematician to the Grand Duke of Tuscany, moving to Florence the same year. Soon thereafter, he also discovered the phases of Venus and sunspots. On the latter, he published the *Sunspot Letters* (Rome, 1613).

Although most of these discoveries were made independently by others, no one understood their significance as Galilei did. This was threefold. Methodologically, the telescope implied a revolution in astronomy in so far as it was a new instrument that enabled the gathering of a new kind of data transcending the previous reliance on naked-eye observation. Substantively, those discoveries significantly strengthened the case in favor of the physical truth of Copernicanism by refuting almost all empirical astronomical objections and providing new supporting observational evidence. Finally, this reinforcement was not equivalent to a settling of the issue, because there was still some astronomical counterevidence (mainly, the lack of annual stellar parallax and the possibility that Venus' phases could support a Tychonic view); because the mechanical objections had not yet been answered and the physics of a moving Earth had not yet been articulated; and because the theological objections had not yet been refuted. Thus, Galilei conceived a work on the system of the world in which all aspects of the question would be discussed. This synthesis of Galileo's astronomy, physics, and methodology was not published until his *Dialogue on the Two Chief World Systems* (Florence, 1632).

This particular delay was due to the fact that the theological aspect of the question got Galilei into trouble with the Inquisition, acquiring a life of its own that drastically changed his life. As it became known that Galilei was convinced that the new telescopic evidence rendered the geokinetic theory a serious contender for real physical truth, he came increasingly under attack from conservative philosophers and clergymen. They argued that Galilei was a heretic because he believed in the Earth's motion and the Earth's motion contradicted Scripture. Although Galilei was aware of the potentially explosive nature of this issue, he felt he could not remain silent, and decided to refute the biblical argument against Copernicus. To avoid scandalous publicity, he wrote his criticism in the form of long private letters, in December 1613 to his disciple **Benedetto Castelli** and in spring 1615 to the dowager Grand Duchess Christina.

Galilei letters circulated widely, and the conservatives became even more upset. Thus in February 1615, a Dominican friar filed a written complaint against Galilei with the Inquisition in Rome. An investigation was launched that lasted about a year. As part of this inquiry, a committee of Inquisition consultants reported that the key Copernican theses were absurd and false in natural philosophy and heretical in theology. The Inquisition also interrogated other witnesses. Galilei himself was not summoned or interrogated partly because the key witnesses exonerated him and partly because Galilei letters had not been published, whereas, his published writings contained neither a categorical assertion of Copernicanism nor a denial of the scientific authority of Scripture.

However, in December 1615 Galilei went to Rome of his own accord to defend his views. He was able to talk to many influential Church officials and was received in a friendly manner; he may be credited with having prevented the worst, in so far as the

Inquisition did not issue a formal condemnation of Copernicanism as a heresy. Instead, two milder consequences followed. In February 1616, Galilei himself was given a private warning by Cardinal Robert Bellarmine (in the name of the Inquisition) forbidding him to hold or defend the truth of the Earth's motion. Galileo agreed to comply. And in March, the Congregation of the Index (the cardinals in charge of book censorship) published a decree, which, without mentioning Galilei, declared that the Earth's motion was physically false and contradicted Scripture, that a 1615 book supporting the Earth's motion as physically true and compatible with Scripture was condemned and permanently banned, and that Copernicus's 1543 book was banned until appropriately revised. Published in 1620, these revisions amounted to rewording or deleting a dozen passages suggesting that the Earth's motion was or could be physically true, so as to convey the impression that it was merely a convenient hypothesis to make mathematical calculations and observational predictions.

For the next several years, Galilei kept quiet about the forbidden topic, until 1623 when Cardinal Maffeo Barberini became Pope Urban VIII. Since Barberini was an old admirer and patron, Galileo felt freer and decided to write the book on the system of the world conceived earlier, adapting its form to the new restrictions. Galilei wrote the book in the form of a dialogue among three characters engaged in a critical discussion of the cosmological, astronomical, physical, and philosophical arguments, but determined to avoid the biblical or theological ones. This *Dialogue* was published in 1632, and its key thesis is that the arguments favoring the geokinetic theory are stronger than those favoring the geostatic view, and in that sense Copernicanism is more probable than geostaticism. When so formulated, the thesis is successfully established. In the process, Galilei's managed to incorporate into the discussion the new telescopic discoveries, his conclusions about the physics of moving bodies, a geokinetic explanation of the tides, and various methodological reflections. From the viewpoint of the ecclesiastic restrictions, Galilei must have felt that the book did not "hold" the theory of the Earth's motion, because it was not claiming that the geokinetic arguments were conclusive; that it was not "defending" the geokinetic theory, because it was merely a critical examination of the arguments on both sides; and that it was an hypothetical discussion, because the Earth's motion was being presented as a hypothesis postulated to explain observed phenomena.

However, Galilei enemies complained that the book did not treat the Earth's motion as a hypothesis but as a real possibility, and that it defended the Earth's motion. These features allegedly amounted to transgressions of Bellarmine's warning and the Index's decree. And there was a third charge: that the book violated a special injunction issued personally to Galilei in 1616 prohibiting him from discussing the Earth's motion in any way whatever; a document describing this special injunction had been found in the file of the earlier Inquisition proceedings. Thus Galilei was summoned to Rome to stand trial, which after various delays began in April 1633.

At the first hearing, Galilei was asked about the *Dialogue* and the events of 1616. He admitted receiving from Bellarmine the warning that the Earth's motion could not be held or defended, but only discussed hypothetically. He denied receiving a special injunction not to discuss the topic in any way whatever, and in his defense he introduced a certificate he had obtained from Bellarmine in 1616 that only mentioned the prohibition to hold or defend. Galilei also claimed that the book did not defend the Earth's motion, but rather suggested that the favorable arguments were inconclusive, and so did not violate Bellarmine's warning.

The special injunction surprised Galilei as much as Bellarmine's certificate surprised the inquisitors. Thus it took 3 weeks before they decided on the next step. The inquisitors opted for some out-of-court plea-bargaining: They would not press the most serious charge (violation of the special injunction), but Galilei would have to plead guilty to a lesser charge (unintentional transgression of the warning not to defend Copernicanism).

Galilei requested a few days to devise a dignified way of pleading guilty to the lesser charge. Thus, at later hearings, he stated that the first deposition had prompted him to reread his book; he was surprised to find that it gave readers the impression that the author was defending the Earth's motion, even though this had not been his intention. He attributed his error to wanting to appear clever by making the weaker side look stronger. He was sorry and ready to make amends.

The trial ended on 22 June 1633 with a sentence harsher than Galilei had been led to believe. The verdict found him guilty of a category of heresy intermediate between the most and the least serious, called "vehement suspicion of heresy"; the objectionable beliefs were the cosmological thesis that the Earth moves and the methodological principle that the Bible is not a scientific authority. The *Dialogue* was banned. He was condemned to house arrest for the rest of his life. And he was forced to recite a humiliating "abjuration."

One of the ironic results of this condemnation was that, to keep his sanity, Galilei went back to his earlier research on motion, organized his notes, and 5 years later published his most important contribution to physics, the *Two New Sciences*. Without the tragedy of the trial, he might have never done it.

Maurice A. Finocchiaro

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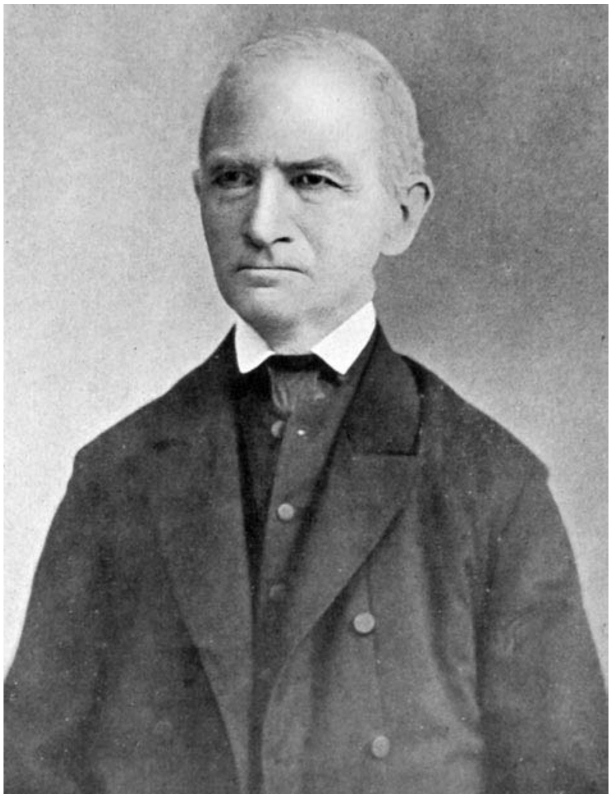
Galle, Johann Gottfried

Born **Pabsthaus, (Sachsen-Anhalt, Germany), 9 June 1812**
Died **Potsdam, Germany, 10 July 1910**



Johann Galle, astronomer at Berlin and Breslau, discovered the planet Neptune and three comets, composed noted catalogs of the orbital elements for comets, and elaborated a new method to measure the solar parallax.

Galle was the eldest of seven children born to Marie Henriette and Johann Gottfried Galle, who earned a living distilling wood to obtain tar and turpentine. After successful studies at the Wittenberg Gymnasium, he matriculated at Berlin University in 1830 to study practical and theoretical astronomy. In 1835, the director of the Berlin observatory, **Johann Encke**, invited Galle to fill the post of his assistant. In 1845, he obtained his doctorate in astronomy from Berlin University, and was appointed as director of Breslau (now Wrocaw, Poland) Observatory in 1851. In 1856, Galle married Cäsilie Eugenie Marie Regenbrecht. Their elder son, Andreas (1858–1943), was an astronomer and geodesist, their younger son, Georg, a physician. Galle remained professionally active into very old age; he served as a professor of astronomy and observatory director at Breslau until 1897.

At the Berlin Observatory, Galle had at his disposal the high-quality 9-in. refractor. In June 1838, while measuring the diameter of Saturn, he discovered the crepe ring of Saturn. His search for comets was remarkably successful; in the brief interval from December 1839 to March 1840, he discovered three new comets. On 23 September 1846, Galle received a letter from the Parisian astronomer **Urbain Le Verrier** with his prediction of a position for the hypothetical trans-Uranian planet. A half-hour search on the following night yielded his discovery of an uncharted eighth-magnitude object with a tiny disk – the giant planet Neptune.

Galle also enjoyed a solid reputation as an experienced computer. Beginning from his student years, he contributed to the Berlin astronomical ephemeris. In 1847, he published his first catalog of the orbital elements of comets; he later expanded this catalog several times. The last edition of 1894 contained the orbital elements for 414 comets. In 1872, Galle made a very useful proposal to use the minor planets to determine the Sun's parallax. He organized international campaigns for the observations of selected asteroids from different locations in order to measure an asteroid's distance from the Earth, which enabled the estimation of the Earth's distance from the Sun. This method gave the most accurate values for the astronomical unit prior to radar observations of the planets. By chance, Galle was involved in meteoritics; he carefully investigated the large rain of meteorites at Pultusk, Poland, on 30 January 1868.

In 1840, Galle won the Lalande Prize of the Paris Academy of Sciences. Today, he is remembered for his discovery of Neptune and commemorated by the naming of minor planet (2097) and craters on the Moon and Mars for him.

Mihkel Joeveer

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Gallucci, Giovanni Paolo

Born **Salò, (Lombardy, Italy), 1538**
Died **Venice, (Italy), *circa* 1621**

Tutor, writer, translator, and cartographer, Giovanni Gallucci studied in Padua and moved to Venice, where he spent the rest of his life. The range of his activity embraces both scientific and humanistic fields.

In his most important work, *Theatrum Mundi et Temporis* (Theater of the world and time; Venice, 1588), Gallucci presents a general treatment of celestial phenomena, including both astronomical and astrological aspects. He declares the definite intention to clear his discussion of any trace of superstition in order to avoid a conflict with the Catholic Church, which some years before had condemned astrology.

The most noticeable peculiarity of Gallucci's book is given by the 48 maps of Ptolemaic constellations. The maps are represented in trapezoidal projection, and show the brightest stars of each asterism and the corresponding mythological figure. The stars' positions are drawn from **Nicolaus Copernicus**' *De Revolutionibus Orbium Coelestium*. The set of maps of *Theatrum* renders this work one of the first celestial atlases of the modern age.

Davide Neri

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Gambart, Jean Félix Adolphe

Born **Sète, Hérault, France, May 1800**
Died **Paris, France, 23 July 1836**

Jean Gambart became in 1819 an assistant at the Marseilles Observatory, and in 1822 its director. From this underequipped and poorly situated institution, he discovered 13 comets between 1822 and 1833, including the famous one on 9 March 1826 that was independently detected by **Wilhelm von Biela** 10 days earlier. It was Gambart who calculated the period of this comet to be less than 7 years. A lunar crater is named for him.

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Gamow, George [Georgiy] (Antonovich)

Born **Odessa, (Ukraine), 4 March 1904**
Died **Boulder, Colorado, USA, 20 August 1968**

Russian–American theoretical physicist George Gamow was among the very first to take seriously the idea of a hot, dense early Universe and to consider the processes that might occur in it, including nuclear reactions and (as a mentor to **Ralph Alpher** and **Robert Herman**) the production of thermal radiation that was eventually detected.

Gamow began his education in Odessa but moved to the University of Petrograd (later Leningrad and now Saint Petersburg), where his initial study of relativistic cosmology with **Alexander Friedmann** was frustrated by the latter's death. He received a Ph.D. in 1928 for work on aspects of quantum theory. Gamov held fellowships at Copenhagen (1928–1929, 1930–1931) and Cambridge (1929–1930) and a professorship at Leningrad (1931–1933) before leaving the Soviet Union for good. He held a professorship at George Washington University from 1934 to 1956 and at the University of Colorado from 1956 until his death.

Gamow's first major contribution was the understanding of quantum-mechanical tunneling (barrier penetration) required for α particles (helium nuclei) to get out of nuclei like uranium and thorium as these decay to lead. This was a near-simultaneous discovery with that made by Eugene U. Condon and Ronald Gurney. Within the next few years, **Robert Atkinson** and **Friedrich Houtermans** recognized that the same sort of tunneling would allow nuclei to come together and fuse, beginning the modern study of energy production and nucleosynthesis in stars. While at George Washington University, he collaborated with **Edward Teller** on the Gamow–Teller selection rules (which describe another kind of nuclear decay called β) and developed the Gamow functions describing nuclear shapes. In papers in 1940/1941 he, along with Mario Schoenberg, considered the possibility of repeated β decays and inverse β decays in stellar interiors and the neutrinos emitted by the process as a stellar coolant, affecting the subsequent supernova explosions of massive stars. The energy at which a nuclear reaction operator is also called the Gamow peak.

As early as 1935, Gamow considered how heavy elements might be built up from light ones by repeated additions of neutrons alternating with β decays, instead of trying to bring more and more massive nuclei together. In 1946, he suggested that the early hot, dense Universe might be an appropriate site for the buildup of heavy elements in this way. In subsequent work with Alpher and Herman, the Universe was described as arising from a primordial substance, "ylem," which was in fact pure neutrons. Only very gradually did it become clear that neutron addition could not build up heavy elements, because there are no stable nuclei with either five or eight particles. (Thus you make hydrogen and helium, a tiny amount of lithium, and nothing else.) To trace the synthesis of heavy elements in stars (see **Fred Hoyle**) and to reconsider the early universe nuclear reactions starting with an equilibrium distribution of protons, neutrons, electrons, and so forth, rather than pure neutrons, was left to others.

Meanwhile, in 1949, Alpher and Herman published a prediction that processes in the early universe should have left a sea of microwave radiation (the Cosmic Microwave Background Radiation [CMBR]) as their signature. They estimated a temperature of about 5 K for that radiation; when it was found by Arno Penzias and Robert Wilson in 1965, the actual temperature was 2.7 K. Gamow conceivably did not take the prediction very seriously at the time, and he advised a potential graduate student with an interest in microwave spectroscopy to look elsewhere for a thesis project. Even after the discovery, at a 1967 conference, he was heard to mutter, "I lost a nickel; you found a nickel. Who's to say it's the same nickel?"

In the early 1950s, Gamow also developed an interest in molecular biology and how heredity might work. He is generally thought to have come very close to the idea of the double helix at the same time James Watson and Francis Crick were developing it. A 1954 paper was one of the first suggestions for how the four nucleotides in DNA might code in triplets for the 20 amino acids widely used by living creatures. Gamov founded a discussion group in the field that had precisely 20 members at any time, so that each could carry the name of an amino acid, and carefully arranged things so that his came first in the alphabet.

Gamow was an outstanding popularizer of science. Among his 30 books, the most widely influential were probably *Our Friend the Sun* (which begins "The sun is much, much larger even than an elephant") and the "Mr. Tompkins" series, which explained quantum mechanics and relativity by imagining a Universe in which Planck's constant was a large number and the speed of light a small one, so that everyday objects displayed quantum mechanical and relativistic effects. His sense of humor carried across into his science, with the neutron process named URCA after the Casino in Rio de Janeiro, where money vanished as steadily as the energy carried away by the neutrinos. Gamow produced a spoof paper purporting to distinguish how the Coriolis force affected the chewing of cud by cows in the Northern Hemisphere and Southern Hemisphere. He failed to get Mr. Tompkins on the author list of one of his papers, but scored a success when he and Alpher were about to submit a paper on the synthesis of the elements from ylem. He looked at "Alpher and Gamow," decided that "something was missing," and added **Hans Bethe** in the middle, with a footnote explaining that the middle author appeared *in absentia*." The footnote was lost from the published version, and "Alpha, Beta, Gamma" have been famous ever since in the astronomical community not just as the three kinds of radioactive decay (or the first three letters of the Greek alphabet) but as an early key paper in cosmology. It is only a few paragraphs long.

Gamow was elected to the United States National Academy of Sciences, the Soviet Academy of Sciences, the Royal Danish Academy, and the International Academy of Astronautics. He was a fellow of the American Physical Society and several others.

Douglas Scott

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Gan De

Flourished **China, 4th century BCE**

According to tradition, Gan De was a native of the state of Chu—he was also said to be a native of the state of Qi or Lu—in the Warring States period (475–221 BCE). He wrote treatises entitled *Tianwen xinzhan* (New astrological prognostications of the patterns of the heavens), in eight volumes, and *Suixing jing* (Canon of the planet Jupiter), but both are lost. Fortunately, some paragraphs from these works were quoted in later books. We can therefore study some of Gan De's achievements in astronomy from the surviving quotations. These achievements can be summed up in two statements.

First, independent of **Shi Shen** (another astronomer of his time), Gan De observed stars and obtained their latitudes and differences in right ascension. He then composed a star atlas including the Chinese constellations. Later on, there appeared a new atlas called *Gan Shi xing jing* (Gan's and Shi's classic of stars), which was based on Gan's atlas and Shi Shen's atlas; it greatly influenced the development of astronomy in China. Recent research has shown that the polar distances and right ascensions of the stars found in *Xing jing* were probably measured around the year 70 BCE, not during the Warring States Period as traditionally thought.

Second, Gan developed the concept of the synodic period of a planet and obtained such periods for Mercury (136 days), Venus (587.25 days), and Jupiter (400 days) (versus present values of 115.9, 583.9, and 398.9 days, respectively). There is some discussion that Gan De may have observed the brightest satellite of Jupiter.

Li Di

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Gaṇeśa

Born **Nandigrāma (Nandod, Gujarat, India), 1507**
Died **probably after 1560**

Gaṇeśa was the founder of a fifth school of astronomical thought during the late period of Indian astronomy. The brief remarks in Gaṇeśa's and his commentators' works tell us that he was born into a Brāhmaṇa family belonging to the Kauśika gotra (a form of exogamous kin-group). His father was the noted astronomer **Keśava;** his mother was Lakṣmī. Gaṇeśa appears to have spent his entire life in Nandigrāma. The number of noted astronomers and astrologers in his family indicates that this practice was their hereditary profession or "caste." Gaṇeśa learned this profession from his father and composed his earliest known astronomical work (according to legend) when he was 13. More than a dozen works are ascribed to him, including treatises and commentaries on mathematics, prosody, and other subjects as well as those on astronomy, astrology, and astronomical instruments.

By far the most important of Gaṇeśa's compositions were the *Grahalāghava* or *Siddhāntarahasya* (Brevity [in] Planet [computations]) of 1520 and the *Laghutithicintāmaṇi* (Wishing-Gem of Lunar Days) of 1525. The former belongs to the class of astronomical handbooks, or *karaṇas*, that provided concise and simple rules for computing planetary positions and astrologically significant phenomena such as eclipses and conjunctions. These requirements were fulfilled with great ingenuity in the *Grahalāghava*. Remarkably, the work employs no trigonometry; the trigonometric solutions to problems of planetary motion are all replaced by algebraic approximations. The *Grahalāghava* is also unusual because of the direct relationship of its selection of astronomical parameters to observation. Instead of adhering strictly to the traditions of any one of four principal astronomical schools, Gaṇeśa chose parameters for his handbook from more than one school, where they agreed most closely with his own observations. This new combination of parameters subsequently formed the basis of a fifth astronomical school that bore Gaṇeśa's name.

The *Laghutithicintāmaṇi* also illustrates Gaṇeśa's interest in, and talent for, ingenious mathematical devices to simplify the labor of routine astronomical computations. It consists of a set of tables for the use of calendar-makers, whose task was to list the dates and times of the beginnings of the several different time-units in the Indian calendar, many of which had ritual or astrological significance. The tables of the *Laghutithicintāmaṇi* supply all the necessary information for this purpose, with a mere 18 verses of directions for their use.

The convenience and simplicity of the methods in the *Grahalāghava* and the *Laghutithicintāmaṇi* made the new "Gaṇeśa School" highly popular in the 16th century and thereafter, especially in the northern and western parts of India. Some scholars of classical Indian astronomy, however, have complained that the influence of these works undermined astronomers' understanding of the relevant theoretical models, as their practical tasks were reduced to the application of fewer and simpler algorithms, thanks to Gaṇeśa's ingenuity.

Gaṇeśa's other astronomical works, chiefly on observational instruments and astrology, did not have the same impact, although his detailed and insightful commentaries on the mathematical and astronomical works of **Bhāskara II** were widely known.

Kim Plofker

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Gaposchkin, Sergei [Sergej] Illarionovich

Born **Yevpatoriya, (Ukraine), 12 July 1889**
Died **Chelmsford, Massachusetts, USA, 17 October 1984**

Russian–American stellar astronomer Sergei Gaposchkin devoted his professional career to the study of variable stars, especially eclipsing binary and spectroscopic binary stars. The son of a day laborer and one of 11 children, he completed his elementary school education before traveling to Moscow in 1915 to work in a textile factory.

In 1917, he was called for military service and Gaposchkin returned to his hometown to enlist. His military service in the Tsar's army, spent as a sergeant on the Galician Front (then part of the Austro–Hungarian Empire), ended with the collapse of the Russian autocracy. After walking for several months from the front back to his military depot in the Crimea to turn in his rifle, Gaposchkin spent a few months serving in the police force in his hometown, continuing his studies at night when possible.

When both his parents and his older siblings died in a typhus epidemic, Gaposchkin was appointed guardian for his remaining brother and sisters. But in October 1920, on a coasting trip from Yevpatoriya to the Sea of Azov, the sailing vessel in which he and his companions were transporting flour was blown off course and weathered a ferocious storm that carried them to Bulgaria. Finally they sailed down to Constantinople, where they sold the remains of their goods and were trapped by the collapse of the White Armies when the Russian Revolution ended.

Without papers or funds, Gaposchkin worked as a gardener and odd-jobs man until a Russian émigré society helped him to travel to Berlin, Germany, where he enrolled in the German Institute for Foreigners, to learn German to fulfill the educational requirements for joining the university. By 1928 he matriculated at the Kaiser Wilhelm University, where he completed his Ph.D. in astronomy in 1932. During the 1920s, Berlin was a vibrant and highly cultured city that attracted many prominent scientists, among them **Albert Einstein**, one of his professors in the Physics curriculum of the Kaiser Wilhelm University. Other professors whose lectures he attended included Ludwig Bieberbach, **Paul Guthnick**, **August Kopff**, and **Max Planck.** During this period he met colleagues such as W. Becker with whom he formed lifelong friendships.

In 1931/1932 Gaposchkin made a survey of variable stars at the remote Sonneberg Observatory, as part of his duties as an assistant at the Babelsberg Observatory near Berlin. During the time he spent at the Babelsberg Observatory, he lived in a single room in the nearby town of Nowawes. But in 1933, with the rise to power of Adolph Hitler, Gaposchkin lost his position and believed that he was scheduled to be sent to a concentration camp at Sonneberg. He was also unable to return to the Soviet Union because he had left Russia during the civil war. By chance he heard from a colleague about the meeting of the Astronomisches Gessellschaft to be held in Göttingen that August. In hopes of finding another position outside Germany, Gaposchkin bicycled to the meeting where he met many scientists, among them Cecilia Payne (later **Cecilia Payne-Gaposchkin**), who would argue his case with the director of the Harvard College Observatory, **Harlow Shapley.** Within a few months, he received a position as research assistant at the Harvard College Observatory, left Germany on a stateless passport, and passing through Britain, took the *Georgic* to Boston, arriving on 27 November 1933. Sergei and Cecilia (who was UK born) married in 1934, and both became American citizens as soon as possible. Two of their three children, Peter and Katherine (Haramundanis), have been involved in astronomy, the latter coauthoring an introductory textbook with her mother.

Gaposchkin spent the rest of his working life at the Harvard Observatory, with occasional extended trips for observing to McDonald Observatory in Texas, USA, and Mount Stromlo Observatory, Australia. During the 1940s, he observed fairly regularly at the Agassiz Station of Harvard Observatory in Harvard, Massachusetts. Gaposchkin was also a gifted artist, working primarily with pencil and watercolors; his sketches of profiles were exceptionally good, and his small landscapes and meticulous Christmas cards, delightful.

Gaposchkin's work in astronomy, much of it done with Cecilia Payne-Gaposchkin at the Harvard College Observatory, was focused on variable stars. His particular specialty was eclipsing binaries, the subject of his Ph.D. dissertation at the University of Berlin. Eclipsing binaries, along with visual binaries, are a source from which the masses of individual stars can be determined. Though somewhat eclipsed by his more brilliant wife, he was fascinated by variables and novae all his life. Gaposchkin published numerous papers on individual variables, and invented the "flyspanker," a small piece of glass on a wand with graduated ink spots, which he and his assistants could use in making estimates of variable stars when adequate comparison stars were wanting. His systematic methods for making observations on photographic plates enabled the Gaposchkins to complete several large investigations of variable stars including that of the Milton Bureau program of Harvard Observatory and a systematic analysis of variables in the Small Magellanic Cloud in which he and his assistants made over a million observations. Additionally, he translated the seminal work *Moving Envelopes of Stars* by Viktor V. Sobolev (Harvard University Press, 1960) from Russian, made visual estimates of the brightness of the Magellanic clouds, and drew a unique picture of the visual Milky Way from observations made on his trip by sea to Australia.

Gaposchkin's correspondence can be found in the Russell Papers, Princeton University; Otto Struve Papers, University of Chicago; and Jesse Greenstein Papers, California Institute of Technology. A three-volume, self-published autobiography of Gaposchkin can be found at Harvard and in a few other collections.

Katherine Haramundanis

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Garfinkel, Boris

Born **Rjev, Russia, 18 November 1904**
Died **West Palm Beach, Florida, USA, March 1999**

Russian American dynamicist Boris Garfinkel formalized the Ideal Resonance Problem in orbital theory.

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Gascoigne, William

Born **Middleton, (West Yorkshire), England, *circa* 1612**
Died **Marston Moor near Long Marston, (North Yorkshire), England, 2 July 1644**

William Gascoigne was the first to use crosshairs in telescopes and invented the wire micrometer. Gascoigne was the eldest child of Henry Gascoigne and Margaret Jane Cartwright, prosperous members of the gentry from Thorpe-on-the-Hill, near Leeds in Yorkshire. Gascoigne's family was likely Catholic. He spent most of his life in Middleton, although John Aubrey claims that he was trained by the Jesuits in Rome. After Gascoigne's death his papers passed to another prominent Yorkshire Catholic family, the Towneleys.

Gascoigne quickly learned astronomy with little formal training. After a brief and uninspiring stay at Oxford, he pursued advanced astronomical studies on his own. Like his contemporary **Jeremiah Horrocks**, Gascoigne repudiated ancient authority and even disagreed with **Philip Lansbergen**'s tables. Gascoigne was determined to make new calculations based on fresh observations. Gifted in the construction and use of astronomical instruments, he made his own Galilean telescope by 1640 and described it in a letter to one of his correspondents, William Oughtred. Gascoigne also invented his own methods for grinding glass and apparently had "a whole barn full of machines or instruments."

Gascoigne's role in positional astronomy went unnoticed for decades. He was the first to discover the use of crosshairs in observational astronomy. He thought of the idea when he observed spider hairs in his telescope. His and others' early crosshairs were usually made of hair or textile thread. By 1640, Gascoigne had introduced crosshairs (telescopic sights) into the focal plane of the "astronomical" telescope: A telescope with a convex eyepiece was necessary for Gascoigne's inventions. He also applied the telescope and telescopic sights to positional measuring instruments (arcs) such as the quadrant and sextant, and the wire micrometer and the micrometer's application to the telescope.

Gascoigne was also the first to invent and apply the wire micrometer to the telescope. Consisting of two parallel hairs (or metal bars), screws with turning parts, and some type of internal scale, micrometers measured small angular distances and apparent diameters of planets. Gascoigne's micrometer consisted of two thin pieces of metal mounted parallel to each other on screws that opened and closed the two blades. The number of revolutions needed to attain a required opening was shown on a scale and the fractions of a revolution on a dial that was divided into a 100 parts. Unlike later micrometers, Gascoigne used two screws on both sides of his device—each screw moved its own reticule either toward or away from the center axis in the field of view.

In a 1640 letter, Gascoigne informed Oughtred that he had "either found out, or stumbled" onto an invention "whereby the distance between any of the least stars, visible only by a perspective glass, may be readily given 1/4 to a second." Gascoigne later described this new mechanical device as "a ruler with a hair in it, moving upon the centre of a circular instrument graduated with transversal lines and two glasses." He told Oughtred that he had shown his "internal" scale "and its use in a glass" to others who were impressed by the invention because they thought that all possible means for taking measurements had been exhausted.

Gascoigne also corresponded with **William Crabtree**, another north country astronomer and friend of Horrocks. News between Horrocks and Gascoigne, who never corresponded directly, filtered through Crabtree, and the three rarely met, though they maintained a fruitful and rewarding correspondence. Gascoigne was killed while fighting on the Royalist side in the Battle of Marston Moor.

A small group of his friends, including Oughtred and Christopher Towneley, kept most of his papers, letters, and records of his inventions, but did not immediately publicize his work. Knowledge of Gascoigne's invention of telescopic sights was even more limited than his micrometer work because he had not shared these results with Oughtred. Consequently, it was forgotten until his papers came to Christopher Towneley's nephew Richard. In 1665, Richard Towneley reintroduced Gascoigne's work, although **Robert Hooke** and **Christopher Wren** had already begun experimenting with telescopic sights by the same year. In the summer of 1671, **John Flamsteed** visited Towneley and viewed the papers. Flamsteed was impressed with Gascoigne's manuscript of a treatise on optics that Gascoigne had intended to send to the press. Unfortunately, the treatise has not survived.

In the late 1660s, priority disputes broke out between the English and French over who first discovered micrometers and telescopic sights. In 1717, **William Derham** responded to the French claims of having discovered telescopic sights in the *Philosophical Transactions of the Royal Society*. Derham felt he was "Duty bound, to do that young but ingenious Gentleman, Mr. Gascoigne, the Justice, to assert his invention to him." He also claimed that Richard Towneley sufficiently proved that the invention of the micrometer was Gascoigne's and not **Adrien Auzout**'s or **Jean Picard**'s, adding that "Gascoigne was the first that measured the Diameters of the Planets, &c. by a Micrometer," and "he was the first that applied Telescopick Sights to Astronomical Instruments."

Voula Saridakis

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Gasparis, Annibale de

Born **Bugnara, (Abruzzo, Italy), 9 November 1819**
Died **Naples, Italy, 21 March 1892**

Annibale de Gasparis was a professor, observatory director, and specialist on minor planets, of which he discovered seven. He was the son of Angelo de Gasparis and Eleonora Angelantoni. In 1838 he moved to Naples in order to attend the courses in the *Scuola di ponti e strade* (School of bridges and roads), an engineering university, but in 1840 he became *alunno* (student) at the observatory of Naples. In 1846 the University of Naples honored de Gasparis with a degree "*ad honorem*" for his studies on the orbit of the minor planet (4) Vesta, which had been discovered by **Heinrich Olbers** in 1807. In 1848, de Gasparis married Giuseppina Russo, and they had nine sons, of whom three died in infancy.

On 19 April 1849, de Gasparis discovered a new asteroid, one that he named Igea Borbonica (*Borbonica* in honour of Ferdinand II of the Borbones, then king of the two Sicilies). The grateful king awarded de Gasparis a life annuity. When the Borbones were dismissed, the asteroid's name–and the life annuity–disappeared. De Gasparis continued his research on minor planets and discovered (11) Parthenope and (13) Egeria (1850), (15) Eunomia (1851), (16) Psyche (1852), (24) Themis (1853), (63) Ausonia (1861), and (83) Beatrix (1865).

For these discoveries the Royal Astronomical Society made de Gasparis a member (in 1851) and awarded him a Gold Medal. In 1858 he became Professor of Astronomy in the University of Naples, and in 1864 he became director of the astronomical observatory of Naples.

De Gasparis published about 200 scientific papers on mathematics, celestial mechanics, astronomy (especially on Kepler's problem), and meteorology. In 1861 he was appointed senator of the Kingdom of Italy. He was member of the Société Philomatique (Paris); Royal Astronomical Society (London); and the Academies of Naples, Modena, Turin, and many others. On his death de Gasparis was widely mourned for his humane qualities as well as his research.

Ennio Badolati

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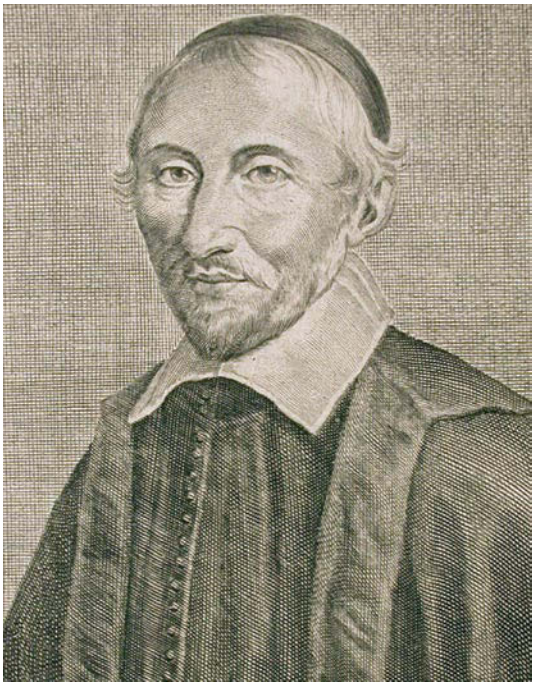
Gassendi, Pierre

Born **Champtercier, (Alpes-de-Haute-Provence), France, 22 January 1592**
Died **Paris, France, 24 October 1655**

Among the most celebrated philosophers of his century, Pierre Gassendi was one of three surviving children born to Antoine Gassend and Françoise Fabry, a humble farm family from the south of France.



Educated initially by his uncle Thomas Fabry, Gassendi later studied at Digne (1599–1606) and Aix (with Philibert Fesaye, 1609–1612) before being appointed canon and finally Principal of the Collège of Digne in 1612. After receiving his *doctorat* in theology from Avignon in 1614 (under Professor Raphaelis), Gassendi was ordained priest and accepted the chair in philosophy at Aix, which he held from 1616 to1623. Here Gassendi lodged with Joseph Gaultier, then the most noted astronomer in France. During this time Gassendi also visited Paris (April 1615) where he first met **Nicolas-Claude Fabri de Peiresc**, his later patron. Gassendi traveled widely in his middle years, living in Provence (1625–1628) and Grenoble (1628–1634), visiting Paris and the Netherlands (1628–1630), and later dividing his time between Provence (1634–1641) and Paris (1641–1648). Gassendi's final years were spent in Provence (till 1653) and Paris, where he revised his major works, among them the *Animadversiones* (later called *Syntagma*, 1658).

Gassendi is best remembered as a Mechanical Philosopher. As the traditional counterpoint to **René Descartes**, Gassendi was an Epicurean atomist and mitigated skeptic who opposed the corpuscularism and dogmatism of the Cartesians. Stridently anti-Aristotelian, Gassendi sought to rehabilitate the ancient atomism of **Epicurus** but also drew on the skeptical philosophies of Sextus Empiricus, Michel de Montaigne, and Pierre Charron. As an empiricist, Gassendi sought a "science of appearances" based on sense experience and probability, thus opposing Descartes' rationalism and innate ideas. Arguing that the inner nature of things could not be known, Gassendi insisted that appearances were beyond doubt and sufficient for establishing the New Science. Descartes retorted that this was the philosophy of a "monkey or parrot, not men."

Gassendi's principal scientific interest was astronomy. A skilled observer, Gassendi was a mainstay of the French *école provençale* and a founding member of the *école parisienne* (or Paris Circle). An early but prudent Copernican, Gassendi was an active and able observer eager to coordinate and compare telescopic observations. Over the course of his career he owned a number of instruments, among them five Galilean telescopes of good quality, as well as several quadrants (5-, 2-, and 1.5-ft radii). One of his first telescopes came from **Galileo Galilei**, though his best lenses were made by **Johannes Hevel** (Hevelius) (1648, 4.5 ft.) and **Eustachio Divini** (1653). When visiting Aix, he also had access to Peiresc's five telescopes. Like others of his generation, Gassendi used mainly Galilean not Keplerian telescopes, which did not come into wide use until after his death.

Gassendi corresponded with astronomers all across Europe. During his second trip to Paris (1628–1632) he visited the famous Cabinet Dupuy where he made lifelong friendships with **Marin Mersenne**, François Luillier (a patron with whom he lived), Gabriel Naudé, Claude Mydorge, and the young astronomer, **Ismaël Boulliau**. During this time, he also met Hevelius, who was then visiting Paris with his mentor, the astronomer Peter Krüger. Thereafter, Gassendi actively contributed astronomical observations to the correspondence networks of Peiresc, Mersenne, Boulliau, and Hevelius, an overlapping network that included Galilei, **Christian Severin** (Longomontanus), **Philip Lansbergen**, **Gottfried Wendelin**, **Maarten Van den Hove** (Hortensius), **Wilhelm Schickard**, **Christopher Scheiner**, and dozens of other scholars, including Thomas Hobbes, Gui Patin, **Willibrord Snel**, and Samuel de Sorbière. Significantly, Gassendi was among the first in France to maintain a journal of astronomical observations (1618–1655), though many of his manuscripts, letters, and observations remain unpublished.

Gassendi's interest in astronomy was linked from the outset to the "optical part of astronomy." He recognized that practical astronomy was based on observation, and as a skeptical philosopher, his theoretical oncerns ran deep. If all knowledge is based on observation—and all appearances are true—then the "play of light" was serious business. These interests are evident throughout Gassendi's career, from his early years (*Parhelia sive soles*, 1630), his middle years (*De Apparente*, 1642), and in his posthumous publications (*Syntagma*, 1658). Halos, coronas, rainbows, and the "Moon illusion" were crucial tests for establishing an empiricist epistemology. That meant rethinking the foundations of astronomy and optics—disciplines where light and vision converged.

Gassendi's international reputation was tied to the transit of Mercury (7 November 1631), a "rare and beautiful phenomenon" with important theoretical implications. In his *Admonitio ad astronomos* (1629) **Johannes Kepler** had advised astronomers to observe the transit in order to confirm Mercury's elongated elliptical orbit and unequal motions. Further, transit observations would be useful for establishing the dimensions of the Solar System, perhaps even the Copernican theory itself. But sky conditions throughout Europe were poor, and Gassendi was all but alone in tracing Mercury's path. Gassendi's method was based on the principle of a *camera obscura*. Projecting the image of the Sun through a telescope on to a screen, Gassendi marked times of ingress and egress, while an assistant noted the solar altitude. Some of the results were unexpected. In his *Mercurius in sole visus* (Paris, 1632) Gassendi admitted that he almost mistook Mercury for a sunspot, due to its unexpectedly small diameter (some 20″). Only three other astronomers observed the transit, **Johann Cysat,** J. -R. Quietan, and an anonymous Jesuit in Ingolstadt, but their observations were imprecise and of little use. Gassendi's observations showed that the tables of Severin erred by over 7°, the Prutenic by 5°, and the Rudolphine by 14 min.

Gassendi's interest in astronomy was never more focused than in his collaborations with Peiresc, particularly during the years 1631–1637. Among the publications that resulted from their research, largely on the "optical part of astronomy," was Gassendi's *De Apparente magnitudine* (Paris, 1642). Here Gassendi defended his atomist views in optics and vision against a cross section of four carefully selected combatants: against the Aristotelian views of two friends, F. Liceti and G. Naudé; against the polite but vague views of Jean Chapelain; and finally, against his friend Boulliau, who defended Kepler's punctiform analysis. For his part, Gassendi proposed a "materialist" theory of light, pointedly combating the "mathematicians"—those content to describe light as geometrical rays rather than to explain light, as Gassendi proposed, as physical body. Similar themes underlie Gassendi's *Solstitialis Altitudo Massiliensis* (1636).

Peiresc's death in 1637 marked a turning point in Gassendi's career. Suffering from depression, Gassendi recovered slowly, thereafter devoting several precious years to writing his friend's biography, *Vita illustris* (Paris, 1641), a classic of the genre. During this difficult interlude, Gassendi obtained another patron, L. -E. de Valois, the new Governor of Provence (1638). Among his closest friends, Valois was Gassendi's most prolific correspondent (some 350 letters). But Valois was less interested in science than Gassendi's earlier patrons; his letters were often short and officious, and, significantly, Valois placed greater demands on Gassendi's time. Upset by the loss of Peiresc—who died having published nothing—Gassendi's sense of urgency increased with the onset of his own illness, a lung ailment (1638) that finally took his life. Unsettled, he departed for Paris (1641–1648). But conflict, both public and private, continued. Antoine Agarrat, Gassendi's longtime assistant in astronomy, soon joined forces with **Jean-Baptiste Morin** in their ongoing pamphlet war, and charges of heresy soon followed.

Gassendi's years in Paris (1641–1648) were nevertheless highly productive. In 1641, Mersenne asked him to supply a critique of Descartes' *Meditations*, and there, in the Fifth set of *Objections*, Gassendi fleshed out differences between Cartesianism and Gassendism. In addition, Gassendi continued to publish works on astronomy, including *Novem stellae circa Jovem visae* (Paris, 1643) and several works on motion, providing one of the first modern statements of the principle of inertia. Now famous throughout Europe, Gassendi was appointed Professor of mathematics at the Collège Royale, but he was soon forced to discontinue his lectures due to poor health. In 1647 Gassendi published his *Institutio astronomica*, a "modern" textbook rivaled only by Kepler's *Epitome* and Descartes' *Principles*. Here Gassendi provided an introduction to astronomy and a comparison of the Tychonic and Copernican models (Book III). Publicly, Gassendi viewed the Tychonic model as a cautious compromise. Privately, his commitment to Sun-centered cosmology was discreet but unswerving.

Following Mersenne's death in 1648, Gassendi again departed Paris for the healthier climate of Provence. Distracted by controversy and discomforted with pain, Gassendi wisely enlisted friends to defend his views (and orthodoxy) against Morin, thus freeing himself to focus on his writing. But as the controversy escalated, Morin predicted Gassendi would die the following year. The prophecy proved false. The following February, accompanied by Luillier and François Bernier, Gassendi climbed the highest peak of Puy-de-Dome (1650). The exercise confirmed Pascal's barometric experiment and gave living proof against judicial astrology.

Gassendi's last years were spent in Paris. Departing Provence in April 1653, Gassendi took residence on the second floor of the Hôtel de Montmor. After the decease of his third patron, Valois, Gassendi enjoyed the support of "Montmor the Rich." Together they established the famous Académie Montmor. During this time Gassendi published several works, among them his biography of **Tycho Brahe** (1654) and a treatise on the eclipse of August 1654.

Robert Alan Hatch

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Gauss, Carl Friedrich

Born **Braunschweig, (Niedersachsen, Germany), 30 April 1777**
Died **Göttingen, (Germany), 23 February 1855**

Carl Gauss is best known for his formulation of the statistical method of least squares. In astronomy, his simplification of the process by which orbits are determined from observations made possible the postconjunction recovery of the first asteroid (1802). The cgs unit of magnetic field intensity, still generally used by astronomers, is named for him.

Gauss was the son of Gebhard Dietrich Gauss (1744–1808) and Dorothea Benze (1743–1839). After attending the gymnasium and subsequently the Collegium Carolinum at Braunschweig, he studied philology and mathematics at Göttingen (1795–1798) and received his Ph.D. in 1799 from the University of Helmstedt. The stipend from the Duke of Braunschweig (since 1792) allowed him to live and work at Braunschweig as a private mathematician. The fame resulting from Gauss's successful computation of the orbit of (1) Ceres laid the ground for his astronomical career. Having declined a call to Saint Petersburg in 1802, he got involved with plans to establish an observatory at Braunschweig. In parallel to his theoretical work, Gauss had started on practical observing quite early, which he continued until 1851. In 1803, he spent several months at the Seeberg Observatory at Gotha to improve his practical proficiency and to enlist **János von Zach**'s help as an advisor for the Braunschweig project. Political developments and finally the death of his sponsor, Duke Carl Wilhelm Ferdinand (from fatal injuries received in the Battle of Jena in 1806), put an end to this endeavor.

In 1805, Gauss married Johanna Osthoff (1780–1809); in 1810 he married Minna Waldeck (1788–1831). He was the father of six children.

Gauss was appointed University Professor and Director of the observatory at Göttingen in 1807. The layout of the new observatory there, finished in 1816, was essentially modeled after Gotha-Seeberg. His earlier experience with astronomical geodesy led to the additional responsibility of director of triangulation for the Kingdom of Hannover (1818–1847).

Already a Fellow of the Royal Society (London), Gauss was one of the first foreign associates elected by the Astronomical Society of London established in 1820. A member of the academies at Göttingen, Saint Petersburg, Berlin, and Paris, he received many other international honors including knighthood in the Danish Dannebrog Order.

The mathematical method developed during Gauss's work on the Ceres recovery problem led to his famous *Theoria Motus* (Theory of the motion of the heavenly bodies moving about the Sun in conic sections, 1809). It remained a basic tool for theoretical astronomy for one and a half centuries. His continuing work on orbit determination, especially on problems encountered with the second known minor planet, (2) Pallas, led to important results in the field of perturbation theory. The *General disquisitions about an infinite series* (*Disquisitiones generales circa seriem infinitam*, 1813), containing the mathematical theory of the hypergeometric series and a general investigation of convergence criteria, was a result of these activities. There followed a tract on numerical quadrature (*Methodus nova integralium valores per approximationem inveniendi*, 1814) and, in 1818, the "Determination of the attraction which a planet exerts on a point of unspecific position …" (*Determinatio attractionis, quam in punctum quodvis positionis datae exerceret planeta …*).

Throughout the first two decades of the 19th century, Gauss's authoritative computations of the orbits of all newly discovered solar-system bodies were of particular importance. Later, other computers (such as **Freidrich Bessel** and **Johann Encke**) took over some of these chores.

Gauss's papers as well as his personal library are held at the Staats- und Universitaetsbibliothek at Goettingen.

Wolfgang Kokott

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Gauss, C. (1809). *Theoria Motus corporum coelestium in sectionibus conicis solem ambientium*. Hamburg. (Gauss's most influential and enduring contribution to theoretical astronomy. Publication of this work, originally written in German, was delayed at the behest of the publisher who wanted a Latin text suitable for an international market. The *Theory of the Motion* was later retranslated into German and translated into several other languages. The first English translation [by Charles Henry Davis] was published in 1857 at Boston; it was reprinted in 1963 [Dover, New York]).

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Trotter, Hale F. (1957). *Gauss's Work (1804–1826) on the Theory of Least Squares*. Princeton. (A good summary of Gauss's theory of least squares, originally published in the *Theoria Motus* as well as several other tracts, is found in this English translation from the French.)

Watson, James C. (1868). *Theoretical Astronomy relating to the motions of the heavenly bodies*. Philadelphia: J. B. Lippincott and Co. (Independent of the original text, the *Gaussian Method* [rendered more suitable for a wider audience by later authors, *e. g.* Encke] was the standard tool presented in the textbook literature of the 19th and 20th centuries—exemplified in this text.)

Gautier, Jean-Alfred

Born **Geneva, Switzerland, 19 July 1793**
Died **Geneva, Switzerland, 30 November 1881**

Jean-Alfred Gautier was a professor of astronomy and mathematics, observatory director, and a prolific author of astronomical articles. The son of François Gautier and Marie De Tournes, he received his basic education in Geneva, then studied science and humanities at the University of Paris, earning his Licentiate in Science in 1812 and in Letters the following year.

Gautier's first and only major work, which was in effect a doctoral dissertation, was a historical essay on the problem of three bodies published in Paris in 1817. He then spent a year in England where he established lasting friendships with many scientific notables, including **John Herschel**. Gautier returned to Switzerland in 1819 to serve as Professor of Astronomy at the Geneva Academy. He strove to improve the Geneva Observatory and eventually secured funding for a new one, which was completed in 1830. Unfortunately, he began to have problems with his eyes at this time, to the extent that he could not carry out observations himself; so with characteristic modesty, he gave up the chair of astronomy and directorship of the observatory to one of his former pupils, Emile Plantamour.

Gautier was married twice but had no children. Two nephews, Emile and Raoul, continued to pursue interests similar to those of their uncle. Gautier was one of the first associate members of the Royal Astronomical Society and the earliest foreign member of the Cambridge Philosophical Society.

Apart from **Edward Sabine** and **Johann Wolf**, Gautier had independently recognized, in 1852, that periodic variations in terrestrial magnetism correlate with the sunspot cycle. The majority of his 200 papers and reviews were commentaries on others' work in almost every field of astronomy, and appeared in the publications of the Société de physique et d'histoire naturelle de Genève: *Bibliothèque universelle des Sciences* or *Archives des Sciences Physiques et Naturelles.* They are conveniently listed in the cumulative index of the latter journal for the period 1846–1878. Gautier's correspondence is in the Bibliothèque publique et universitaire in Geneva.

Peter Broughton

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"Jean Alfred Gautier." *Monthly Notices of the Royal Astronomical Society* 42 (1882): 150–152.

Geddes, Murray

Born **Glasgow, Scotland, 1909**
Died **Glasgow, Scotland, 23 July 1944**

Murray Geddes, along with his family, immigrated to New Zealand at an early age. Later, he obtained an MS in physics and took up a career in teaching. His avocational studies of the Aurora Australis in collaboration with Norwegian physicist **Carl Störmer** showed that southern auroral displays were far more common than had previously been understood and at times exceeded the Aurora Borealis. Geddes photographed the aurora to determine the auroral height, study auroral forms, and strengthen the correlation of auroral activity with sunspots. Recognizing from studies of Antarctic exploration historical records that New Zealand provided the only inhabitable landmass from which auroral studies could be carried out consistently, Geddes organized a corps of 700 auroral observers to assist in these studies. He also made useful contributions to the study of zodiacal light. He was an assiduous meteor observer and discovered comet C/1932 M2, for which Geddes received both the Donohoe Medal of the Astronomical Society of the Pacific and a Donavan Prize and Medal from Australia. Geddes had been appointed director of the Carter Observatory shortly before being called to active duty as a naval reservist. He died while serving in the New Zealand Navy in the North Sea during World War II.

Thomas R. Williams

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Geminus

Born **possibly Rhodes, (Greece), *circa* 10 BCE**
Died ***circa* 60**

Geminus concerned himself largely with dividing mathematics (which then included astronomy) into several divisions and subdivisions.

The belief that Geminus was from Rhodes is largely based on his astronomical works, which use mountains on Rhodes as reference points. However, Rhodes was the center of astronomical research at the time; it is conceivable that Geminus simply referenced these points from prior knowledge, and it is thus distinctly possible that he was not a native of the island. He was either a direct pupil or a later follower of **Posidonius** and is considered a Stoic philosopher. Geminus is mentioned in works by **Simplicius** and is accused of simply rewriting Posidonius. There is enough of Geminus' original work surviving for this accusation to be untrue.

Geminus' primary contribution to astronomy included some philosophical musings. He said that astronomy dealt with facts and not causes, and proceeds from hypotheses. He gave several examples of such reasoning in relation to astronomy in his works, which included a commentary on Posidonius' *Meteorologica* and a work that was clearly his own, *Isagoge* (Introduction to astronomy). In it he made some interesting contributions to astronomy. In particular, he introduced the concept of mean motion, and represented the motion of the Moon in longitude by an arithmetical function. In addition, the work mentions the zodiac, the solar year, the irregularity of the Sun's motion, and the motions of the planets. In dealing with the zodiac, Geminus discussed the 12 signs, the constellations, and the axis of the Universe. He spoke of eclipses, the lunar phases, and the calendar.

Ian T. Durham

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Gemma, Cornelius

Born **Louvain, (Belgium), 28 February 1535**
Died **Louvain, (Belgium), 13 October 1578 or 12 October 1579**

Cornelius Gemma was the son of **Gemma Frisius** and Barbara, and followed in his father's footsteps. His first teacher was M. Bernhardus, the supervisor of a school in Mechelen, where Gemma stayed at least during the years 1546–1547. Around 1549, at the age of 14, he matriculated at the Faculty of Arts at Louvain University, and 3 years later, on 26 March 1552, he was promoted. By 1561, Gemma called himself "medicus" in the title of his *Ephemerides*, which he published from 1560 onward for 5 consecutive years. Although Gemma was nominated *regius professor* at the university in 1569, as the successor to Nicolas van Biesen (Biesius), he was only promoted to doctor of medicine on 23 May 1570. On 9 November 1574, he was nominated ordinary professor (*professor ordinarius*) and succeeded Charles Goossens (Goswinus) of Bruges.

Around 1561, Gemma married the daughter of Judocus (Josse) Van der Hoeven. They had four children: a boy and a girl died of the plague in the same year as their mother. Their son Philippe was born around 1562 and became bachelor of medicine in 1583. Raphaël was baptized in November 1566 and died in January 1623.

Gemma was in contact with notable people of his time: Antoine Mizauld, Jean Charpentier (Carpentarius), **Tadeá Hájek z Hájku**, and Benedictus Arias Montanus, with whom he was very close. Gemma was known as a physician, a professor, an astronomer, a philosopher, a poet, and an orator. His writings consist of an astronomical and a philosophical–medical part.

In 1556, Gemma completed his father's *De Astrolabo catholico* by adding a preface, a dedication to the Spanish king Philip II, a *carmen panegyricum* on his father's death, and 18 chapters. His *Ephemerides meteorologicae* were published during 5 consecutive years (1560–1564); they mostly include meteorological predictions, but they lack the fundamental basis of daily observations. Gemma's desire to investigate the nature of the phenomena made him revert to the common theories of antiquity. However, after having linked the effects and their causes and having discovered the discrepancies between the data of the Alphonsine tables and the positions of the stars, he expressed his clear preference for the Copernican theory and the *Prutenicae tabulae* over the Ptolemaic and the Alphonsine tables.

Gemma took a major interest in two celestial phenomena that characterized the second half of the 16th century: the new star of 1572 and the comet of 1577. In his writings on both celestial phenomena, he attributed great importance to astrology, and he gave a detailed account of its role in medicine and its influence on human affairs. Gemma's *De Naturae divinis characterismis* (1575) was largely inspired by and devoted to the new star of 1572. He supposed that the star emerged from the invisible depths of space, to which it would eventually return. This amounted to a denial of the principle of circular motion of the heavenly bodies, and likewise to a considerable increase of the volume of the world, exceeding the sphere of the fixed celestial bodies.

Regarding the 1577 comet, Gemma believed that the comet was not located at the border of the Earth's atmosphere (as it should be following the Aristotelian doctrine), but in Mercury's heaven (*De prodigiosa specie naturaque cometae*, 1578). This meant that neither his opinions concerning the new star nor those concerning the comet were in agreement with traditional cosmology, although he used elements of this system (*e. g.*, he discussed "Mercury's heaven" from a geocentric viewpoint).

Gemma also wrote a report on the reform of the Julian calendar. In 1578, Pope Gregorius XIII sent a book by Aloïs Lilius, on the reform of the calendar, to the leaders of the University of Louvain with the request that it be studied by the mathematicians of the

Alma mater. Pierre Beausard and Cornelius Gemma were charged with this task. Although they died of the plague before they were able to present their report, the report carrying the signature of both scholars has been found and was transferred to Rome.

Gemma's philosophical–medical works contain his *De arte cyclognomica tomi III* and his *De naturae divinis characterismis … libri II*. His *De arte cyclognomica* (1569) shows his clear preference for the heliocentric theory, because it corresponded better with the observations. However, Gemma did not explicitly reject the geocentric theory because, in his opinion, it corresponded better with the Bible.

Astrological concerns are clearly present in Gemma's writings. He favored christianized Neoplatonism and had close contacts with cabalists such as Guillaume Postel (1505–1581) and Guy le Fèvre de la Boderie (1541–1598). According to Gemma's view, astrology was within the purview of cosmological semiotics; this is explained in detail in his *De naturae divinis characterismis* (1575). An earlier version of his theory can be found in his *De Arte cyclognomica*. Gemma considered the world to be a living body, all parts of which are connected to each other and mutually influence each other. It was impossible to see the observation of the heavens as unrelated to the observation of the Earth's nature and human society. All the phenomena occurring in one of these three "worlds" were connected with phenomena occurring in the other worlds, and thus became "signs" that required investigation and deciphering by the "cosmocritical art."

Fernand Hallyn and *Cindy Lammens*

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Gentil de la Galaisière, Guillaume-Joseph-Hyacinthe Jean-Baptiste Le

Born **Coutance, (Manche), France, 11 September 1725**
Died **France, 22 October 1792**

G. J. Le Gentil was one of the astronomers to advocate observations of the Venus transit of 1761. As a young man, Le Gentil considered priesthood; however, he broke from his studies one day to hear a lecture by **Joseph Delisle**. This piqued his curiosity about astronomy so much that he soon became a fixture at the Paris Observatory, working under the tutelage of **Jacques Cassini**. By 1753, with his religious studies behind him, Le Gentil was recognized as a professional in astronomy. Especially notable were his writings on the difficulty of determining the initial contact of Mercury as it transited the Sun. This, he reasoned, made it nearly impossible to use the transit as an effective tool to determine the distance between the Sun and the Earth–the Astronomical Unit–though **Edmond Halley** had believed it possible some decades earlier.

Halley had also pointed out that a transit of Venus would provide a better opportunity. Le Gentil believed that Halley's calculations were based on tables that were not sufficiently accurate to determine the exact times and positions for observation. His work on this problem led him to favor the values produced by Cassini. This placed him in favorable light when the French government began to consider sending its astronomers throughout the world to observe the 1761 transit.

For his destination, Le Gentil chose Pondicherry, an area of India controlled at that time by France. He departed for India on 26 March 1760; 3 months later, arriving on the island of Mauritius, he learned that the Indian Ocean was full of British warships, and that Pondicherry was locked in a war with British land forces. Undeterred, Le Gentil talked his way onto a supply ship going there, only to learn, off the Indian coast, that the town had been captured several months earlier. The ship's captain then returned to Mauritius. Heavy seas and far-from-perfect skies gave him terrible views of the event, and his calculations were worthless.

Despite his disappointment, Le Gentil wrote to the Academy of Sciences requesting permission to explore the islands in the Indian Ocean. Thus began a program of natural history, navigation, and geography, mapping the coasts of the islands, doing anything he felt would contribute to the scientific knowledge of the area. When the transit of 1769 was approaching, Le Gentil decided to stay in the area to make up for his previous failure. His calculations suggested that the best observational site was in Manila. In August 1766, after a grueling 3-month voyage, he arrived in Manila, only to learn that the governor wanted no visitors, especially one wanting to establish an astronomical observatory. Le Gentil then sailed for Pondicherry, by now reclaimed by France. He was given permission to set up an observatory in what had been a gunpowder warehouse during the war. He woke on transit day to find gathering clouds, and it remained overcast throughout the day.

Le Gentil was devastated. He waited for the next ship out in October 1769, but contracted a life-threatening fever and missed his ship. Still very ill, he took the ship in March 1770, selecting a Europe-bound ship at Mauritius, which had to return to port after nearly sinking in a storm. Le Gentil finally obtained passage on a Spanish warship, reached Spain, and traveled by land to France, more than 11 years after leaving.

On arriving home, Le Gentil discovered he had been declared dead, his chair at the academy was occupied by another member, and his heirs had divided up his estate. Eventually, he retrieved some of his property, his place in the academy, and married a wealthy heiress, from whom he had a daughter. His memoirs of his adventures were a popular and financial success.

Francine Jackson

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Gerard of Cremona

Born **Cremona, (Italy), *circa* 1114**
Died **Toledo, (Spain), or Cremona, (Italy), 1187**

Gerard's principal contributions were his translations of Arabic texts on astronomy and other sciences. Gerard received his basic education in his native town of Cremona. Then, interest in deeper learning, especially the work of **Ptolemy**, led him to (before 1144) Toledo, where he studied Arabic and devoted himself to translating into Latin some of the Arabic translations of Greek treatises, Arabic commentaries on them, and original Arabic works dealing with astronomy, mathematics, philosophy, medicine, and other sciences.

Gerard is said to have translated 76 works, including the *Almagest* (1175) by Ptolemy, the **Toledo Tables** ascribed to **al-Zarqālī**, *Physics* by **Aristotle,** and different works by **Abū Ibn al-Haytham**, **Ibn Sina**, Jabir ibn Aflah, **al-Farghani**, **al-Kindi**, **Masha'alla,** and others. Some traditional ascriptions that he is credited with are wrong (*e. g.*, the *Theorica planetarum* ascribed also to Gerard Sabionetta). However, like other translators (*e. g.*, **Adelard of Bath**, Hermannus of Carinthia, Johannes Hispalensis, Plato of Tivoli, Robert of Chester), he mediated the knowledge of the achievements of Greek and Arabic science to Medieval Europe—several of his translations were printed in the 16th century—and he thus stimulated its subsequent development.

Gerard was buried at Saint Lucy Church in Cremona.

Alena Hadravová and *Petr Hadrava*

Alternate name

Gerardus Cremonensis

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Gerardus Cremonensis

➤ **Gerard of Cremona**

Gerardus Mercator

➤ **Kremer, Gerhard**

Gerasimovich [Gerasimovič], Boris Petrovich

Born **Poltavian Kremenchug, (Ukraine), 31 March 1889**
Died **Leningrad (Saint Petersburg, Russia), 30 November 1937**

Boris Gerasimovich, Soviet astrophysicist, was active in a broad range of research areas but became a tragic victim of the 1936–1937 purges that were a horrific reality in the USSR of the period. Pulkovo Observatory, of which he was director, suffered more than any other scientific institution, largely due to local circumstances.

Gerasimovich completed his university education at Kharkov University in 1914, where he had studied under **Aristarkh Belopolsky** and Sergei Konstantinovich Kostinsky. He held the position of *Privatdozent* (lecturer) from 1917 to 1922, and was appointed professor at Kharkov University from 1922 to 1931, during which time he was the most senior astronomer at the university observatory. Between 1926 and 1929, Gerasimovich spent a fruitful period in the United States, conducting research, along with the staff of the Harvard College Observatory, and visiting his colleague **Otto Struve** at Yerkes Observatory. In 1931, Gerasimovich returned to Pulkovo Observatory, where he became director in 1933.

Gerasimovich's scientific work, represented by about 170 publications in several languages, addressed many problems in astrophysics and astronomy. He recognized early the crucial importance of interstellar absorption in the calibration of the Cepheid period–luminosity relation, and gave a quantitative explanation of observed variations in Be stars based on a hypothesis of rotation coupled with an expanding shell. He was among the first to conduct detailed studies of planetary nebulae, noting that their different forms were the result of interactions between the gravitational pull of the central star and its outward light pressure. His observations, later confirmed, indicated that the masses of these central stars were not large.

In 1927, with **Willem Luyten**, Gerasimovich determined the distance from the Sun to selected galactic (open) clusters. He likewise developed and improved the theory of ionization for stellar atmospheres and interstellar gas by suggesting modifications to the Saha formulae of thermodynamic equilibrium.

In 1929, with Otto Struve, Gerasimovich observed the physical conditions of interstellar gas and absorption lines created by this gas. In that same year, with **Donald Menzel** (with whom he shared the A. Cressy–Morrison Award of the New York Academy of Sciences), he used statistical mechanics to model the sources of stellar energy. He, along with **Cecilia Payne-Goposchkin**, contributed to an understanding of the temperatures of F stars.

Gerasimovich was one of the first astronomers to consider the astrophysical significance of cosmic rays. He studied several types of variable stars extensively, by observing their periods and the forms of their light curves. Gerasimovich took part in several solar eclipse expeditions, and was president of a special commission of the USSR Academy of Sciences to prepare unified expeditions to observe the total solar eclipse of 19 June 1936. He wrote the monograph, *Solar Physics*, published in Ukrainian (1933) and in Russian (1935).

However, the later Stalinist purges in 1936–1937 devastated Russian astronomy and destroyed Pulkovo as an active research institute. Following a stormy campaign against him, both by colleagues who found him difficult and by influential amateurs with their own political agendas, Gerasimovich was accused of crimes related to noncompliance with Marxist–Leninist ideology, and of philosophical errors, including being under foreign influence because he had published papers in non-Soviet journals. While the vituperative campaign was under way, he remained as director of Pulkovo and offered twice to resign. But his credibility was tarnished by the Voronov scandal and by the coerced confession of **Boris Numerov**, who tragically implicated nearly the entire staff of the observatory. The effect on Russian astronomy was to be felt for decades. The Academy of Sciences commissions appointed to investigate the problems at Pulkovo included the Astronomy Council that met in October 1937 to condemn the arrested scientists. They may have wished to shield Gerasimovich but his principal accuser, Vartan T. Ter-Organezov, was adamant and so effectively criticized the Astronomical Council that it was dissolved in December.

Gerasimovich was arrested on 30 June 1937 on the train while returning from Moscow to Leningrad and imprisoned. Following a meeting on 30 November 1937 of the Military Collegium of the Supreme Court of the Soviet Union, he was found guilty and executed that day in Leningrad. For years, his name vanished even from official histories of Russian astronomy.

Gerasimovich received awards from the Soviet Union (1924, 1926, and 1936) and from France (1934). A crater on the Moon, and minor planet (2126), are named after Gerasimovich.

Katherine Haramundanis

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Gersonides: Levi ben Gerson

Born **Bagnols, (Gard), France, 1288**
Died **probably Provence, France, 20 April 1344**

Gersonides left few letters and does not talk about himself in his writings; nor is his life discussed at great length by his contemporaries. He may have lived for a time in Bagnol sur-Ceze. It is probable that his father was Gershom ben Salomon de Beziers, a notable mentioned in medieval histories. Though Gersonides made several trips to Avignon, he most likely spent his entire life in Orange. There is some evidence that he may have followed the traditional occupation of his family, moneylending. With the decline of Spanish Judaism in the 13th century, Provence quickly became the cultural center for Jewish intellectual activity. The popes in Avignon had a lenient policy toward the Jews, whose creative life flourished, particularly in philosophy and theology. Although Gersonides spoke Provençal, his works are all written in Hebrew, and all of his quotations from **Ibn Rushd**, **Aristotle**, and **Maimonides** are in Hebrew as well. He may have had a reading knowledge of Latin; he appears to manifest an awareness of contemporary scholastic discussions. Gersonides might, however, have learned of such discussions in oral conversations with his Christian contemporaries.

Although Gersonides wrote no scientific works as such, scientific discussions were included in his philosophical works. Gersonides' major scientific contributions were in the area of astronomy; his works were known by his contemporaries, both Jewish and Christian. One of the craters of the Moon, Rabbi Levi, is named after him. Gersonides' astronomical writings are contained primarily in Book 5, part 1 of *The Wars of the Lord* (Milḥamot ha-Shem), his major philosophical *opus*, which was completed in 1329. The astronomical parts of *The Wars* were translated into Latin during Gersonides' lifetime. Although the astronomy chapters were conceived as an integral part of the work, they were omitted in the first printed edition of *The Wars* but have survived in four manuscripts. In the 136 chapters of Book 5, part 1 of *The Wars*, Gersonides reviews and criticizes astronomical theories of the day, compiles astronomical tables, and describes one of his astronomical inventions.

With respect to his astronomical observations, what distinguished Gersonides from his Jewish philosophical predecessors was his reliance upon and consummate knowledge of mathematics, coupled with his belief in the accuracy of observations achieved by the use of good instruments. Because of this rootedness in empirical observation, which was bolstered by mathematics, Gersonides believed that he had the tools to succeed where others had failed, particularly in the area of astronomy.

That Gersonides clearly considered his own observations to be the ultimate test of his system is explicit from his attitude toward **Ptolemy**. "We did not find among our predecessors from Ptolemy to the present day observations that are helpful for this investigation except our own" (*Wars* V.1.3, p. 27), he says, in describing his method of collecting astronomical data. Often, his observations do not agree with those of Ptolemy, and in those cases he tells us explicitly that he prefers his own. Gersonides lists the many inaccuracies he has found trying to follow Ptolemy's calculations. Having investigated the positions of the planets, for example, Gersonides encountered "confusion and disorder," which led him to deny several of Ptolemy's planetary principles (Goldstein, 1988, p. 386). He does warn his colleagues, however, to dissent from Ptolemy only after great diligence and scrutiny. It is interesting to note that Gersonides briefly discusses, and then dismisses, the heliocentric model of the Universe before rejecting it in favor of geocentrism (*Wars*, Chapter 51; also Commentary on Deuteronomy, 213c).

Gersonides is perhaps best known for his invention of the Jacob's Staff. This instrument, which he called *Megalle ʿamuqqot* (Revealer of profundities) and which was called *Bacullus Jacobi* (Jacob's staff) by his Christian contemporaries, is described in detail in Chapters 4–11 of *Wars* 5.1. The material contained in these chapters was translated into Latin in 1342 at the request of Pope Clement VI and survives in a number of manuscripts. Gersonides' instrument was used to measure the heights of stars above the horizon. It consisted of a long rod, along which a plate slides, that could be used to find the distance between stars.

Gersonides was interested in other instruments as well, including the astrolabe for which he suggested several refinements, and the camera obscura. The latter instrument was used by him for making observations of eclipses. Gersonides also applied the principle of the camera obscura to make a large room into an observing chamber, taking advantage of the image cast by a window on the opposite wall.

Chapter 99 of Book 5, part 1, contains astronomical tables commissioned by several Christian clerics. Besides containing a general explanation of the tables, Chapter 99 contains instructions on how to compute the mean conjunction and opposition of the Moon and Sun; a method for deriving the true conjunction or opposition of the Moon and Sun; a computation of solar time; and a discussion of eclipses, with tables for positions of the Moon for each day.

In Book 5, part 2, of *The Wars*, which was included in most manuscripts, Gersonides deals with technical, albeit nonmathematical, issues in astronomy, such as the interspherical matter (*Wars* 5.1, Chapter 2); topics concerning the diurnal sphere, the Milky Way, and the movements of the planets (*Wars* 5.1, Chapters 4–5, 7–9); and how the Sun heats the air (*Wars* 5.1, Chapter 6). In Book 5, part 3, Gersonides examines a number of additional topics, such as the Aristotelian question of how many celestial spheres are needed to explain the movements of the heavenly bodies (*Wars* 5.3, Chapter 6), and whether the velocities of the heavenly bodies are related by a commensurate number (*Wars* 5.3, Chapter 10). In this context, Gersonides addresses Ptolemy's theory of cosmic distances based on a system of nested spherical planetary shells. He introduces a fluid layer ("the matter that does not keep its shape") between two successive planetary shells so that motion of one planet would not affect the motion of the planet adjacent to it. Gersonides then computes the planetary distances according to three separate theories (*Wars* 5.3, Chapters 130–135).

Gersonides was also an avid supporter of judicial astrology, which plays an important role in his philosophical views on free will and providence. The treatise, *Pronosticon de conjunctione Saturni et Jovis et Martis*, was started by Gersonides (possibly at the request of Pope Clement VI) and completed by his Latin translator, Peter of Alexander, and Levi's brother, Solomon. This work is a prediction based on the conjunction of Saturn and Jupiter to take place in March 1345. Gersonides himself died in 1344, a year before the event in question. In his prognostication, Gersonides predicts a number of calamitous events. The Black Death, which arrived in Europe in 1347, was thus provided with numerous astrological credentials.

In short, according to Gersonides the ultimate function of astronomy is to understand God. Astronomy, he claims, can only be pursued as a science by "one who is both a mathematician and a natural philosopher, for he can be aided by both of these sciences and take from them whatever is needed to perfect his work" (*Wars* V.1.1, p. 23). Astronomy, he tells us, is instructive not only because of its exalted subject matter, but also because of its utility to the other sciences. By studying the orbs and stars, we are led ineluctably to a fuller knowledge and appreciation of God. Astronomy thus functions as the underpinning of the rest of his work.

Tamar M. Rudavsky

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Gilbert, Grove Karl

Born **Rochester, New York, USA, 6 May 1843**
Died **Jackson, Michigan, USA, 1 May 1918**

Grove Gilbert was the first individual to articulate a cogent theory of lunar crater formation as a consequence of meteoroid impacts, resulting in structures that were patently different than craters of volcanic origin observed on the surface of the Earth. One of the most respected American geologists of his generation, Gilbert trained in mathematics and classical languages at the University of Rochester, graduating in 1862. After a brief stint as a schoolteacher in Michigan, he spent 5 years sorting specimens as a clerk at Ward's Scientific Establishment, a scientific factory in Rochester known, in true Humboldtean fashion, as Cosmos Hall. In 1869, Gilbert obtained a position as a volunteer with John Strong Newberry's Geological Survey of Ohio.

Gilbert's work with Newberry was followed in 1871 by an appointment to Lieutenant George M. Wheeler's wide-ranging army survey of that wonderland of geology, the American Southwest. Gilbert's reports on these research expeditions already showed the development of his basic approach. His "systematic geology," as his biographer Stephen J. Pyne put it, proceeded "by an arrangement of careful, systematic contrasts, in which various geologic regions, or systems, or various geologic processes are compared with respect to their fundamental similarities and differences." As Gilbert himself described it, he preferred wherever possible to make general statements rather than to draw up mere lists of facts.

In 1875, Gilbert joined the US Geological and Geographical Survey of the Rocky Mountain Region led by Major John Wesley Powell, the one-armed veteran of the Civil War who had achieved fame for his daring exploration of the Colorado River as far as the Grand Canyon. It was under Powell's direction that Gilbert carried out his most important investigations as a member of the Geological and Geographical Survey, and later as a geologist of the US Geological Survey.

In 1891, Gilbert's survey work led him to Coon Butte (also known as Coon Mountain) near Canyon Diablo in northern Arizona, and thence to his study of the Moon. Now known as "Meteor Crater," Coon Butte consists of an arid plain whose scanty soils lie atop beds of limestone. The plain is described in the following manner:

> [I]nterrupted by a bowl-shaped or saucer-shaped hollow, a few thousand feet broad and a few hundred feet deep…. In other words, there is a crater; but the crater differs from the ordinary volcanic structure of that name in that it contains no volcanic rock. The circling sides of the bowl show limestone and sandstone, and the rim is wholly composed of these materials.

Following the discovery of iron at the site, it was visited by a prominent mineralogist, A. E. Foote, who presented his findings at a meeting of the American Association for the Advancement of Science in Washington on 20 August 1891. Gilbert, present at the meeting, heard Foote suggest the iron was of celestial origin—the remnant of a shower of meteorites. "I asked myself," he later wrote, "what would result if another small star should now be added to the Earth, and one of the consequences which had occurred to me was the formation of a crater, the suggestion springing from the many familiar instances of craters formed by collision."

Gilbert's tests in the field, especially his failure to detect the deflection of a magnetized needle, led him to conclude against the falling star theory. Instead, he decided the crater had been formed explosively by steam—in short, it was a volcanic feature of the type known as a *maar*. He would never discuss Coon Butte again—publicly at least—though it remained the subject of intensive study by others and would eventually and conclusively be shown to be an impact feature. But it was Coon Butte that led directly to Gilbert's interest in the craters of the Moon.

Indeed, almost immediately after his return to Washington, Gilbert turned the 26-in. refractor of the US Naval Observatory and his geologically trained eye to the Moon. Gilbert found he could not support the analogy invoked by so many earlier writers, for example, **Johann von Mädler**, **Johann Schröter**, **James Nasmyth**, and **James Carpenter**, between terrestrial volcanoes and the lunar craters with their landslip terraces and central peaks. The terrestrial volcanoes were closely grouped around a certain maximum size, as though constrained by a limiting condition, while the larger lunar craters were widely scattered about a maximum, like aberrant shots deviating from the bull's eye. Even more significant were the differences in form. Craters of the Vesuvian type, which included 95% of terrestrial craters, were formed by lavas containing considerable amounts of water. As the lava rose, this water was converted into steam, and by the propulsive power of steam the lava was torn to pieces and hurled high into the air. Repeated episodes of this process—intermittent explosions followed by periods of quiescence—formed a conical mountain with a funnel-shaped cavity at its summit. Such craters, however, had little in common with those of the Moon. Gilbert noted that the bottoms of lunar craters are almost invariably lower than the surrounding plain; conversely, the bottom of the Vesuvian crater lies higher than the outer plain.

In short, geological features of the Earth known to be of volcanic origin were not at all like the lunar craters. By the process of elimination he was left with the meteoritic impact theory. There were, of course, objections to be overcome, especially the sheer scale of the lunar craters. Gilbert admitted that it was "incredible that even the largest meteors of which we have direct knowledge should produce scars comparable in magnitude with even the smallest visible lunar craters." Earlier theorists had been forced to suggest that at one time such meteors were much larger than what we now observe. As no evidence had been found that the Earth was subjected to a similar attack, the lunar bombardment had to be assigned to an epoch more remote than all the periods of geologic history—an epoch so remote that similar scars on Earth had been obliterated entirely by the forces of water and wind.

With the help of physicist Robert Simpson Woodward (1849–1924), Gilbert worked out many details of the impact process. "In the production of small craters by small moonlets," he wrote, "I conceive the bodies in collision either were crushed or were subjected to plastic flow and in either case were molded into cups in a manner readily illustrated by laboratory experiments with plastic materials. The material displaced in the formation of the cup was built into a rim partly by overflow at the edges of the cup, but chiefly by outward mass movement in all directions, resulting in the uplifting of the surrounding plain into a gentle conical slope."

Central peaks were formed by the recoil. The rays emanating from some of the more prominent and fresher-appearing craters were splash features, consisting of material thrown out from the impact that formed them.

Gilbert's most elegant piece of work was his identification of what he called "sculpture"—a pattern of parallel grooves or furrows and smoothly contoured oval hills whose trend lines all converged on a point located near the middle of Mare Imbrium impact basin.

Gilbert's seminal 1892 paper "On the Face of the Moon" seems startlingly modern. Indeed, he deserves to be called the Champollion of the Moon—after Jean François Champollion, the French Egyptologist who completed the decryption of the famous Rosseta Stone. With the insight of genius, he had presented a unified view of the Moon's incredibly diverse and hitherto largely unintelligible detail. But Gilbert was too far ahead of his time; for decades his work was virtually ignored until it was validated and extended by **Ralph Baldwin** and Eugene Merle Shoemaker (1928–1997).

It must be noted that Gilbert's work on lunar cratering theory constituted an extremely small component of his scientific oeuvre. Gilbert was a powerful figure in late 19th-century American science, so important in fact that the National Academy of Sciences [NAS] chose to identify him as the most important American scientist in the first century of that organization's existence. His NAS biographical memoir is, accordingly, the longest such memoir ever published.

Thomas A. Dobbins

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Gilbert [Gilberd], William

Born **Colchester, Essex, England, 1544**
Died **probably London, England, 1603**

William Gilbert is best known today for his study of magnets and magnetism, in which he discusses (among other things) the Earth's magnetic field.

Gilbert was the eldest son of Jerome [Hieron] Gilberd, recorder of Colchester. William entered Saint Johns College, Cambridge, and obtained a BA (1561), an MA (1564), and finally an MD (1569). He became a Junior Fellow of Saint Johns in 1561, and a Senior Fellow in 1569. Some authors suggest that he also studied in Oxford, but this is not established. On leaving Cambridge, Gilbert probably undertook a long journey on the continent (likely in Italy). He then settled in London in 1573 to practice medicine. He was elected that same year a fellow of the Royal College of Physicians and was in turn Censor (1581/1582, 1584–1587, and 1589/1590), Treasurer (1587–1591, 1597–1599), Elector (1596/1597), Consilarius (1597–1599), and President (1600) of the College. Gilbert participated in the compilation of the College of Physicians' *Pharmacopoeia*. His medical career was very successful, and he was one of the prominent physicians in London. Near the end of his life, he became one of the personal physicians to Queen Elizabeth I (1600–1603). After the death of Queen Elizabeth (24 March 1603), he continued as royal physician to King James I and kept this position until his own death by plague 8 months later.

Gilbert's achievement as a doctor would have been enough to secure his fame, but he is best remembered today for his book *De Magnete* (written in Latin). In this book, published in London in 1600, he presents investigations on magnets. *De Magnete* provides a review of what was known about the nature of magnetism, as well as knowledge added by Gilbert through his own experiments. Gilbert is sometimes quoted as the father of experimental research and *De Magnete* described him as the first exemplar of modern science. Gilbert devoted long sections of his book to a critical examination of earlier ideas about the magnet and the compass. The distinction between earlier discoveries and his own input, however, is not always obvious in the text. Gilbert refuted many folk tales, including the medicinal properties of magnets to cure all sorts of headaches, the effect of garlic to weaken the magnetic properties of the compass needle, or even the possibility of a perpetual motion machine. Gilbert also described as "vain and silly" the idea of "magnetic mountains or a certain magnetic rock or a distant phantom pole of the world." Relying on many experiments, Gilbert drew analogies between the magnetic field of the Earth and that of a *terrella* (Gilbert's word for a spherical lodestone). He studied the magnetic dip (*declinatio* in Gilbert's word) near the *terrella*, and conjectured that "the Earth globe itself is a great magnet" (*Magnus magnes ipse est globus terrestris*); however, rigorous demonstration of the internal origin of the geomagnetic field was only given by **Carl Gauss** in 1838. Gilbert also proposed to determine longitude and latitude using magnetic dip and declination (*Variatio*).

De Magnete is divided into six "books." The progression is remarkable. In book III, Gilbert neglected declination to simplify his task. Then he started book IV by reintroducing this notion: "So far we have been treating direction as if there were no such thing as variation." This sort of simplification has now become a rather classical scientific approach, but it was not at that time. The final book (VI) concerned stellar and terrestrial motions. In this book, Gilbert departed somewhat from the scientific rigor that characterizes his work. Guided by the fact that magnetic North and astronomical North are so close, Gilbert suggested that the Earth's rotation was due to its magnetic nature. Gilbert described as "philosophers of the vulgar sort (…), with an absurdity unspeakable" those that believed the Earth to be stationary. He expected the dipole nature of the Earth's magnetic field to add support to the Copernican theory. Because of this book, Gilbert is sometimes considered as one of the earliest Copernicans; his ideas influenced **Johannes Kepler** also.

A second book, *De mundo nostro sublunari philosophia nova*, was published (and coauthored) posthumously in 1651, by one of Gilbert's brothers. This lesser-known text includes a map (or rather a sketch) of the Moon drawn by Gilbert (before the telescope).

Emmanuel Dormy

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Gildemeister, Johann

Born **Bremen, (Germany), 9 September 1753**
Died **Bremen, (Germany), 9 February 1837**

Johann Gildemeister of Bremen was a prominent member of **János von Zach**'s "Himmel Polizei" ("Celestial Police").

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Giles of Rome

Born **Rome, (Italy), *circa* 1247**
Died **Avignon, France, 22 December 1316**

Giles' significance in the history of astronomy lies in his metaphysical investigations into such fundamental physical notions as matter, space, and time.

Giles was the most significant theologian of the Order of the Augustinian Hermits in the 13th century. His exact date of birth is uncertain, as is his alleged relation to the noble family of the Colonna (which is not mentioned in contemporary sources). He entered the Augustinian order at a young age, about 1260. Later, Giles was sent to study in Paris, where he probably was among the students of **Thomas Aquinas** from 1269 to 1272, and started writing his commentary on Peter Lombard's *Sentences*, as well as extensive commentaries on **Aristotle**'s works. If one can believe the traditional, yet often debated attribution, it was also during this period, around 1270, that he composed *De Erroribus Philosophorum*, the compilation of the philosophically doubtful and theologically condemnable positions of Aristotle, **Ibn Rushd, Ibn Sina, Abū al-Ghazali, al Kindi**, and Rabbi Moses **Maimonides**. This work was very much in agreement with the spirit of the 1270 condemnations issued by Stephen Tempier, the Bishop of Paris. Nevertheless, in 1277, Tempier's zeal found even Giles' doctrine suspect on several counts. But Giles' troubles did not prevent King Philip III from entrusting him with the education of his son, the future Philip the Fair. Giles' immensely influential political work, *De Regimine Principum*, dates from this period, and is dedicated to his royal student.

By 1281, Giles returned to Italy, where he started to play an increasingly important role in his order. Yet, in 1285, upon the reexamination of his teachings, Pope Honorius IV asked him to make a public retraction of some of his theses condemned in 1277. The retraction regained for Giles his license to teach, and so in effect it enabled him to exert an even greater influence in his order and beyond. As a result, the general chapter of the Augustinian Hermits held in Florence in 1287 practically declared his teachings the official doctrine of the order, commanding its members to accept and publicly defend his positions. After serving in further, increasingly important positions, in 1292 Giles was elected superior general of his order at the general chapter in Rome. Three years later, in 1295, the new pope, Boniface VIII, appointed him archbishop of Bourges. As an Italian archbishop in France, and a personal acquaintance of the parties involved, Giles had a difficult role in the conflict between Philip the Fair and Boniface VIII, but on the basis of his theological–political principles, he consistently sided with the pope. On the other hand, after Boniface's death, he supported the king's cause against the Order of Templars. In the subsequent years Giles continued to be active in the theological debates of the time, until his death at the papal Curia in Avignon.

Giles' investigations into the nature of matter, space, and time, although usually carried out under the pretext of merely providing further refinements of traditional positions, in fact opened up a number of new theoretical dimensions, pointing away from traditional Aristotelian positions.

For example, Giles' interpretation of the doctrine of the incorruptibility of celestial bodies does not rely on the traditional Aristotelian position of attributing to them a kind of matter (ether, the fifth element, quintessence) that is radically different from the matter of sublunary bodies (which were held to be composed of the four elements, earth, water, air, and fire). Since matter, according to Giles, is in pure potentiality in itself, it certainly cannot make a difference in the constitution of celestial bodies. Therefore, he argued that what makes the difference is that the perfection of the determinate dimensions of these bodies, filling the entire capacity of their matter, renders their matter incapable of receiving any other forms, and that is why they are incorruptible. These determinate dimensions are to be distinguished from the indeterminate dimensions of matter (*dimensiones interminatae*), the dimensions determining a quantity of matter that remains the same while matter is changing its determinate dimensions in the constitution of an actual body, as in the processes of rarefaction and condensation. The distinction is necessitated by considering that if matter is nonatomic, but continuous, genuine rarefaction or condensation (*i. e.*, diminution or enlargement of the actual, determinate dimensions of the same body without the subtraction or addition of any quantity of matter) can take place only if the changing actual dimensions are distinct from the constant quantity of matter. This interpretation of Ibn Rushd's notion of *dimensiones interminatae* as the invariable quantity of matter can be regarded as taking a significant step toward the modern notion of mass.

Similar considerations apply to Giles' metaphysical investigations into the nature of time. Motivated by the Aristotelian argument against the possibility of a vacuum, on the grounds that free fall in a vacuum would have to be instantaneous, in his hypothetical speculations concerning the possibility of instantaneous motion in a vacuum, Giles transformed the Aristotelian notion of time into a more general idea of a succession of instants. This enabled him to distinguish different orders of time, namely, the proper time of the thing moved, which is the intrinsic measure of its successive motion (*mensura propria*), and celestial time, which is the extrinsic measure (*mensura non propria*) of the same motion. Thus, it would be possible for a thing instantaneously moved in a vacuum to cover all intervening spaces successively at different instants of its proper time, which, however, being unextended and not separated by time, may coincide with the same instant of celestial time. This more general notion also enabled Giles to distinguish between time that is the mode of existence of material things, and angelic time, which is the mode of existence of nonmaterial, yet not simply eternal beings.

Gyula Klima

Alternate names

Aegidius Romanus
Aegidius Colonna [Columna]

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______ *Quodlibeta*. Frankfurt am Main: Minerva, 1966.

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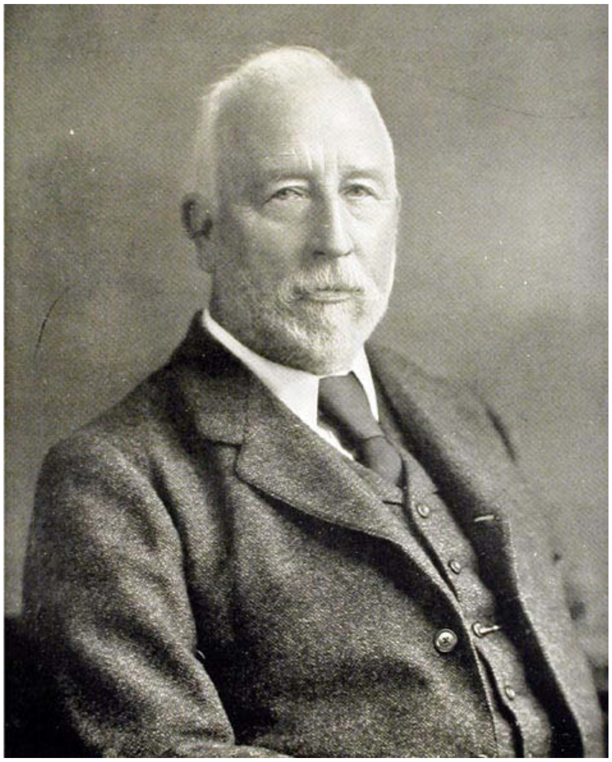
Gill, David

Born **Aberdeen, Scotland, 12 June 1843**
Died **London, England, 24 June 1914**



The career of David Gill, the leading British observer and instrument-minded astronomer of his generation, straddled the introduction of photographic techniques to astronomy. He was born in Aberdeen to David Gill (1789–1878), a clockmaker, and Margaret Mitchell (1809–1870). He had three brothers and a sister who survived infancy. Gill's education was at Bellevue Academy in Aberdeen and, briefly from the age of 14, at Dollar Academy near Stirling. At 15, he entered Marischal College of Aberdeen University, where one of his teachers was **James Maxwell**. As it was intended that he should enter the family firm, Gill underwent practical training in watchmaking in England and Switzerland before joining his father in 1863.

While in business, Gill remained an avid amateur astronomer and possessed a 12-in. reflecting telescope. A photograph that he took of the Moon came to the attention of Lord James Ludovic Lindsay (later Earl of Crawford and Balcarres), who offered him a position as Director of his proposed private observatory at Dun Echt (Aberdeenshire). Although recently married to Isobel Black (died: 1920) of Aberdeen, he accepted this post, which meant a drop in income by a factor of five. Primarily responsible for ordering the equipment for Dun Echt, Gill learned a great deal about astronomical instrumentation; he later became the leading expert on the heliometer. With Lord Lindsay, Gill went on an expedition to Mauritius for the 1874 transit of Venus, with the intention of measuring the Astronomical Unit [AU]. The experience and reputation he gained, as well as his increasing reputation as an astronomer, encouraged Gill to leave Dun Echt. He then resided in London from 1876 to 1879 as an independent astronomer without paid employment. During this period, Gill conducted an expedition to Ascension Island for further observations of Mars. For his early work, especially on his efforts to determine the AU, he received widespread recognition.

In 1879, Gill was appointed by the Admiralty to the position of Her Majesty's astronomer at the Cape of Good Hope, South Africa. On arrival, he found the Royal Observatory in a lamentable state and immediately set about its reorganization, using his own money when the Admiralty would not provide. Gill made plans for a definitive measurement of the AU through observations of minor planets and persuaded the Admiralty to order a new heliometer for this purpose. His measurements in 1889 led to a value of the AU that was accepted for 45 years.

Gill's most important enduring contribution to astronomy derived from an accidental discovery. In 1882, he photographed the great September comet of that year (C/1882 R2) using "dry" plates, a recent development. He was amazed to find that these new plates were sufficiently sensitive to record the background stars in large numbers. He realized that, with a suitable camera, these plates would provide an excellent means for surveying the sky and dramatically increase the speed of cataloging the heavens. Gill's breakthrough revolutionized astronomy, greatly impacting the array of instruments that would soon equip leading observatories.

In 1885, Gill commenced the sky survey known as the "Cape Photographic Durchmusterung," a southern extension of the Bonner Durchmusterung of **Friedrich Argelander**. Because of opposition to this project from the Astronomer Royal, **William Christie**, Gill had to finance it himself, and, with his wife's agreement, he devoted half his salary to the work. The project was completed in 1900, with the measurement of the plates undertaken by **Jacobus Kapteyn** of Groningen.

In the meantime, Gill became involved in the international *Carte du Ciel* program, defined at the 1887 Paris Astrographic Congress, at which he played a leading role, together with Admiral **Ernest Mouchez**, Director of Paris Observatory. The many telescopes used for this program had to be of standard aperture and focal length. Gill contributed actively and in meticulous detail to the design of those supplied to the British Empire observatories by **Howard Grubb**. The Cape Observatory's share of the work absorbed a major part of the its effort for decades.

Gill was acutely aware of the trend toward astrophysical research that had taken root in the 1870s and 1880s and was anxious to make his mark in this area. The Admiralty, interested only in navigation, was not willing to provide equipment for astrophysical investigations, but the Royal Observatory was eventually offered a large (26-in.) refractor and state-of-the-art spectrograph by Gill's friend and admirer, **Frank McClean**. This telescope, completed around 1901, was equipped with a laboratory for making comparison spectra of terrestrial substances.

Admiral Sir William Wharton, the Hydrographer of the Royal Navy and Gill's immediate superior, came to admire Gill's work and acted favorably on proposals he made from about 1895 onward. One of these was for a radically new type of transit circle that Gill designed in detail and that Troughton and Simms constructed. This telescope, installed in 1901, became the pattern for a new generation of such instruments.

The Royal Observatory had been transformed into a model institution by the time Gill retired in 1907. In many ways, it outshone the mother observatory in Greenwich. The number and quality of staff were greatly improved. Gill was able to attract long-term eminent visitors, such as Kapteyn, **Willem de Sitter**, and amateur astrophotographer, **John Franklin-Adams**, who made the southern part of his all-sky survey from the Royal Observatory.

After his retirement, Gill returned to London. There, he took an active part in the Royal Astronomical Society. He completed his monumental history of the Royal Observatory and became a consultant on instrumental matters to various foreign observatories. Gill died in 1914, survived by his wife. He had no children.

Most of Gill's official correspondence is in the Royal Greenwich Observatory Archives, Cambridge University Library. Categories dealing with instrumental and local matters are located at the South African Astronomical Observatory, South Africa (successor to the Royal Observatory).

Ian S. Glass

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Gillis, James Melville

Born **Georgetown, District of Columbia, USA, 6 September 1811**
Died **Washington, District of Columbia, USA, 9 February 1865**

James Gillis, son of George and Mary (*née* Melvile) Gillis, founded the United States Naval Observatory and served as its second superintendent. Gillis' education in astronomy was largely self-directed. He was commissioned in the US Navy and served at sea before being assigned as a Lieutenant to the United States Navy Depot of Charts and Instruments. Working with limited resources from the depot, Gillis published the first star catalog based on American observations (1846).

Gillis began the process of ordering instruments for a first-class observatory, and then persuaded the US Congress that a new facility should be provided to house the instruments. Navy political considerations dictated the appointment of **Matthew Maury** as the first superintendent of the new observatory. Instead, Gillis was assigned for a period of time to the Coastal Survey working with **Alexander Bache** and **Benjamin Peirce**.

On his own initiative, Gillis persuaded the Navy and Congress to equip an expedition to Chile. The expedition's goal was to make simultaneous observations of the oppositions of Mars and Venus from US observatories and from Chile. The intent was to improve upon the value of the solar parallax, or distance from the Earth to the Sun. Neither Harvard College Observatory director **William Bond** nor Maury assigned sufficient priority to the effort; therefore Gillis's efforts fell short of a new determination of the solar parallax. The expedition, which was in Chile from December 1849 to September 1852, was otherwise quite productive, producing many useful measurements and a new catalog of southern celestial objects. The equipment left in Chile resulted in the establishment of Chile's first astronomical observatory.

When Maury fled to the South and joined Confederate forces in the US Civil War, Gillis was promoted to Commander, and eventually Captain, and became the second Superintendent of the Naval Observatory in 1861. Gillis was a founding member of the United States National Academy of Sciences.

Thomas R. Williams

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Gingrich, Curvin Henry

Born **York, Pennsylvania, USA, 20 November 1880**
Died **Northfield, Minnesota, USA, 17 June 1951**

Curvin Gingrich was professor of mathematics and astronomy at Carleton College and third editor of the journal, *Popular Astronomy*, producing its final twenty five volumes (1926–1951).

Gingrich, son of William Henry and Ellen Kindig Gingrich, received his bachelor's degree (1903) and master's degree (1905) from Dickinson College, Carlisle, Pennsylvania. Between 1903 and 1909, he taught mathematics at two Missouri colleges and one Kansas university. In 1909, Gingrich was appointed to the faculty of Carleton College, Northfield, Minnesota, where he spent the remainder of his career. Concurrently, he was admitted to the University of Chicago and earned his Ph.D. in 1912. Thereupon, Gingrich was named full professor of mathematics and astronomy at Carleton. He served in a variety of administrative roles between 1914 and 1919. In 1915, Gingrich married Mary Ann Gross; the couple had one daughter.

Gingrich's research chiefly involved the "older" astronomy of position and motion that best utilized the institution's refracting telescopes. He determined the positions of minor planets and comets by photographic astrometry, measured binary stars, and derived stellar parallaxes. He also conducted stellar photometry. Gingrich was a guest investigator at the Mount Wilson Observatory (1921–1922) and at the Leander McCormick Observatory of the University of Virginia (1935). He lectured part-time at Chicago's Adler Planetarium (1931–1933).

Gingrich was successively named assistant editor of *Popular Astronomy* (1910) under **Herbert Wilson**, associate editor (1912), and editor (1926), upon Wilson's retirement. For eighteen years, he was assisted by colleague **Edward Fath**, who succeeded Wilson as director of the College Observatory in 1926. Under Wilson's and Gingrich's leadership, *Popular Astronomy* became the unofficial journal of the American Astronomical Society [AAS]. During the 1930s and 1940s, Gingrich established a close professional relationship with **Otto Struve**, director of the Yerkes Observatory and editor of the *Astrophysical Journal*. Struve freely contributed to Gingrich's journal, for the sake of preservation of the AAS and the astronomical community as a whole. In spite of severe austerities introduced by the Great Depression and World War II, Gingrich continued publication of *Popular Astronomy* without interruption; the journal celebrated its 50th anniversary in 1943. Afterward, he and Struve were able to witness the reflowering of astronomy in the early postwar period.

Gingrich was due to retire from the College on 30 June 1951 but suffered a fatal heart attack less than two weeks beforehand. While the remainder of the year's issues were fulfilled, *Popular Astronomy* ceased publication after December 1951 and was never resumed by any other institution.

Selected papers and correspondence of Gingrich are preserved in the Carleton College Archives.

Jordan D. Marché, II

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Ginzburg [Ginsberg], Vitaly Lazarevich

Born **Moscow, Russia, 4 October 1916**

Soviet theoretical physicist Vitaly Ginzburg was one of the three founders of the modern Russian school of theoretical astrophysics (along with **Joseph Shklovsky** and **Yakov Zel'dovich**). He has made important contributions to the understanding of the origin of cosmic rays, of nonthermal radiation from the Sun, supernova remnants, and quasars, and of the nature of compact astrophysical objects. Ginzburg was the son of an engineer father and physician mother (who died when he was 2); an only child, he was largely raised by his mother's younger sister. He was educated at home for several years, received 4 years of formal secondary schooling, and then (because 7 years of education was thought to be enough in those days) became a laboratory assistant in an X-ray diffraction lab. After a couple of tries, Ginzberg was admitted to Moscow State University through a competitive examination in 1934, receiving a first degree from the physics faculty in 1938; a candidate's degree in 1940 for work that started out as experimental optics under S. M. Levi, but rapidly developed into theoretical investigations of the quantum theory of Vavilov–Cerenkov radiation (an important source of X-rays and γ rays from astronomical objects) and other topics in quantum radiation theory; and a Doctor's degree in 1942 for a thesis on the theory of higher spin particles.

In 1940, Ginzberg was appointed to a position in the department of theoretical physics of the P. N. Lebedev Physical Institute of the USSR Academy of Sciences, where he has worked ever since, apart from 2 years near the beginning of World War II, when Academy scientists were evacuated to Kazan. The department was headed for many years by Igor Tamm, and then, following his death in 1971, by Ginzburg for the next 18 years. The best known of his younger associates and *protégés* were probably L. M. Ozernoi, S. I. Syrovatsky, and V. V. Zhelezniakov.

As part of his war work, Ginzburg considered the propagation of radio waves in the Earth's ionosphere, and plasma physics in general. Thus, when he was asked to work out how the hot corona of the Sun might reflect radar signals sent from Earth, the calculation was a familiar one, and led to his first official astronomical paper, pointing out that solar radio emission must come from the corona, not the photosphere, and suggesting possible emission mechanisms for both quiescent and radio burst radiation. The latter is synchrotron radiation in large measure, and credit for recognizing this must be somehow divided between Ginzburg and Shklovsky.

Another of Ginzburg's prescient ideas was the suggestion that the radiation from a compact part of the Crab Nebula (it was not known to be a pulsar in 1965) must arise from some coherent, nonthermal process. He was also an early advocate of nonthermal mechanisms for radio galaxies and in rejecting the idea from **Walter Baade** and **Rudolph Minkowski** that Cygnus A was a pair of galaxies colliding.

Ginzberg pointed out in early 1965 that the diffuse gas between the galaxies (the intergalactic medium) would necessarily be at temperatures larger than 10^5 K simply because of the energy sources available to it. Observational evidence showing that this must be true appeared later in the year in the form of observations of the quasar 3C9 by Maarten Schmidt and interpretation by James Gunn and Bruce Peterson. Ginzberg's association between cosmic rays and supernovae and their remnants was also one of the first serious echoes of the ideas of Walter Baade and **Fritz Zwicky** in 1934.

Ginzburg's level of recognition was somewhat spotty. He published more than 1,000 papers, and was, for many decades, the most cited Soviet physicist after **Lev Landau** (whose textbooks trained generations of physicists in every country). Ginzburg was elected a corresponding member of the Soviet Academy of Sciences (1953) and a full member in 1966 primarily in recognition of work on the Soviet fusion bomb project (which remained secret for many years), for which he received the Order of Lenin and the Stalin Prize in the early 1950s. He was the George Darwin lecturer of the Royal Astronomical Society in 1974, but was not allowed to travel to England to give the lecture. He was also elected the founding president of the International Astronomical Union Commission on High Energy Astrophysics in 1970, but again was generally not able to participate in its meetings.

Virginia Trimble

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______ (2001). *Physics of a Lifetime*. Berlin: Springer.

Giovanelli, Ronald Gordon

Born **Grafton, New South Wales, Australia, 1915**
Died **Sydney, New South Wales, Australia, 27 January 1984**

In 1946, Australian astronomer Ronald Giovanelli theorized that solar flares occur through magnetic field reconnection.

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Glaisher, James

Born **Rotherhithe, (London), England, 7 April 1809**
Died **Croydon, (London), England, 7 February 1903**

James Glaisher's early professional years were spent as an observational astronomer at the Cambridge University Observatory, and then at the Royal Observatory, Greenwich. He is principally remembered for his major contributions to meteorology.

The details of Glaisher's early years and education are somewhat obscure. His father, James Glaisher (1786–1855), is said to have been a watchmaker. James Jr. was the eldest of nine children; soon after his birth the family moved from the dockland area of Rotherhithe downriver to Greenwich. There, the Glaishers met William Richardson, an assistant to Astronomer Royal **John Pond**.

Richardson introduced Glaisher, and later his brother John Glaisher (1819–1846), to the observatory. James Glaisher was not at first employed there, but around 1829 received some instruction in the use of instruments prior to his appointment to the Ordnance Survey of Ireland in that year. The combination of wet weather and exposed mountain triangulation points damaged his health and forced his resignation from the survey at the end of 1830. (Thirteen years later Glaisher suffered a long bout of rheumatism after studying the formation of dew on damp grass at night.)

Glaisher recovered sufficiently by 1833 to be appointed first assistant to **George Airy** at Cambridge, where he assumed responsibility for the newly installed great mural circle, making nearly all the observations from 1833 to 1835. He is also credited with observations of Halley's comet (IP/Halley) with the Jones equatorial from 2 September 1835 to 16 January 1836. When Airy became Astronomer Royal at Greenwich in September 1835, Glaisher remained in Cambridge to reduce his 1835 observations and did not go to the Royal Observatory until February 1836, though his appointment at Greenwich was effective from 1 December 1835. With Airy's encouragement Glaisher continued in the reduction of earlier Greenwich and Cambridge observations of the stars, Sun, Moon, and planets, leading to the publication of a star catalog and corrections to the elements of the orbit of Venus. Glaisher was elected a fellow of the Royal Astronomical Society [RAS] in 1841, and expected and wished to continue as an established astronomer, but Airy decreed otherwise.

The Royal Observatory had established a separate division to make observations of terrestrial magnetism in 1838, intending at first to operate it for only a few years. In 1840, Airy assigned Glaisher to the new facility. However, it was determined in 1843 that there should be a permanent Magnetical and Meteorological Department, independent of the astronomical operations. Glaisher was to superintend this new department until his retirement in 1874. He accepted the challenge of this new career, and although he continued to take an interest in astronomical matters, remaining a fellow of the RAS for 63 years, Glaisher effectively became an atmospheric physicist (in modern terms) from 1840 onward. The main features of this second career are mentioned in brief.

Glaisher carried out important researches into the radiation from the ground into space at night. At the same time he transformed a scattered body of amateur weather observers over the country into a national network, regularly reporting observations made with calibrated instruments on a uniform plan. Glaisher initiated a system in which observations were taken at railroad stations at 9:00 a.m. daily and forwarded on the next train to London. The collated nationwide data were published the following day in the *London Daily News* beginning in June 1849. Two years later, an experimental system of telegraphic transmission permitted same-day publication of the data and weather maps. Between 1862 and 1866, Glaisher made a series of 29 balloon ascents for scientific purposes, which brought him international fame; on 5 September 1862 (without oxygen) Glaisher lost consciousness at about 30,000 feet and probably attained a slightly higher altitude. His pilot/companion on these flights was Henry T. Coxwell.

The Royal Society [RS] elected Glaisher as a fellow in 1849, Airy having proposed him for this honor. In 1850, three RS fellows, Glaisher and two wealthy friends of his, Samuel Charles Whitbread and John Lee (proprietor of the Hartwell House private observatory), joined with seven RAS fellows to create the British Meteorological Society (later with a Royal Charter). Apart from his presidency from 1867 to 1868, Glaisher served as secretary of the Meteorological Society until 1873. He published an account of the severe winter of early 1855. His microscopical studies of the shapes of snow crystals (necessarily made at low temperatures), with drawings made by his artist wife, are still often reproduced.

The relationship between Glaisher, the assistant, and Airy, his director for over 40 years, was unusual. Airy, only 8 years Glaisher's senior, had a brilliant academic career; Glaisher was largely self-taught. Both came from modest backgrounds, and had made their way in the world by the single-minded pursuit of knowledge and a fierce determination; both had become opinionated and unyielding in the process. They disliked one another, but admired each other's better qualities. The end came in 1874, when Airy tactlessly rebuked his colleague for leaving work 10 min early on one occasion. Glaisher promptly handed in his resignation by formal letter, and retired from Greenwich on the adequate pension earned by his long service. In retirement, Glaisher had much to occupy him for a further 29 years. He was a well-known writer and was immersed in the activities of several learned societies and committees of public affairs. Glaisher eventually moved to Croydon, near London, with a private observatory there.

In 1843, Glaisher had married the much younger Cecilia, daughter of the Greenwich assistant Henry Belville, who was of French descent; the marriage was not entirely happy, and his wife predeceased him in 1892. There were three children. The eldest son, **James Whitbread Lee Glaisher**, who was given the names of two of his father's wealthy scientific friends, shared much of the ability and interests of his father and became a fellow of the Royal Society as a distinguished and prolific mathematician and mathematical astronomer.

In the 1860s, a nearside lunar crater at latitude 13°.2 N, longitude 49°.5 E was named to honor Glaisher's achievements as a meteorologist.

David W. Dewhirst

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Glaisher, James Whitbread Lee

Born **Lewisham, Kent, England, 5 November 1848**
Died **Cambridge, England, 7 December 1928**

James Whitbread Lee Glaisher was a pure mathematician and mathematical astronomer who served in leadership positions in the Royal Astronomical Society for 55 years.

The eldest son of the English astronomer/meteorologist **James Glaisher**, young Glaisher attended Saint Paul's School in London and then Trinity College, Cambridge, where, in 1871, he graduated as second wrangler. He won the Campden Exhibition in 1867 and the Perry Exhibition in 1869. In 1871, Glaisher was elected to a fellowship and a lectureship in mathematics at Trinity College and held these positions until 1901. He received a D.Sc. degree from Cambridge in 1887, the first year that the degree was offered at the university.

Glaisher became a fellow of the Royal Astronomical Society [RAS] shortly before his graduation in 1871, and was elected to the society's council in 1874. He was reelected to the council continuously and was in the middle of his 55th year of service when he died. Glaisher served two terms as president of the society (1886–1888 and 1901–1903), several terms as a vice president, and as secretary from 1877 to 1884. He served as president of the Royal Astronomical Society Club (an informal but exclusive dining arrangement) for 33 consecutive years. In 1875, Glaisher was elected a fellow of the Royal Society.

Glaisher's notable service to the RAS notwithstanding, he came under attack as secretary, as did **Arthur Ranyard**, during a decade-long struggle by professional astronomers who wished to appropriate the RAS as a strictly professional organization. The dissidents, led by **William Christie**, characterized themselves as "working astronomers" and "practical astronomers" and objected to having their papers screened by anyone who was not so qualified. Efforts were made, at different times, to recall both secretaries and replace them in spite of their obvious qualifications. The recall elections failed in both cases, but after Christie became one of the secretaries, control of the society by the professional astronomers accelerated.

Upon the retirement of **George Airy** as Astronomer Royal in 1881, the position was offered to Glaisher, because of his eminence as a mathematical astronomer, but he turned it down. Instead, the appointment went to Christie.

In his mathematical career, Glaisher published approximately 400 papers, mostly on the history of mathematical subjects. He was well known and respected for his history-of-mathematics papers, especially on the history of the plus and minus signs and his *Encyclopedia Britannica* article on logarithms. Many of his papers provided detailed analyses and uses of various elements of mathematics. Overall, Glaisher's papers were rated by scholars as generally good, but of uneven quality. In the first 2 years after his graduation from Trinity College, he published 62 papers. Glaisher served as the editor of the *Quarterly Journal of Mathematics* (1879–1928) and the *Messenger of Mathematics* (1871–1928). He authored the 174-page report by the Committee on Mathematical Tables for the British Association for the Advancement of Science in 1873. This paper detailed the history of mathematical tables, cataloged existing tables, and updated many other tables as necessary. Glaisher edited the *Collected Mathematical Papers of Henry John Stephen Smith*.

In 1872, Glaisher joined the London Mathematical Society and was elected to the society's council in the same year. He served on its council until his retirement in 1906. Glaisher served as the society's president for the years 1884 to 1886.

The earliest of many mathematical–astronomical papers that Glaisher wrote was his 1872 paper "The Law of the Facility of Errors of Observations and on the Method of Least Squares" published in the *Memoirs of the Royal Astronomical Society*. His interests in astronomy probably came from his father, who served under Airy at Cambridge Observatory (1833–1838) and at Greenwich (1838–1874), until he retired in 1874 after being offended by Airy.

In 1900, Glaisher served as president of the British Association for the Advancement of Science. He served on several of the association's mathematical committees and edited volumes 8 and 9 of its *Mathematical Tables*.

Among his numerous awards and honors, Glaisher received the De Morgan Medal from the London Mathematical Society in 1908, the Sylvester Medal of the Royal Society in 1913, and honorary D.Sc degrees from Trinity College of Dublin (1892) and Victoria University of Manchester (1902). He was an honorary fellow of the Manchester Literary and Philosophical Society, the Royal Society of Edinburgh, and the National Academy of Sciences in Washington.

Glaisher was a renowned collector and authority on English pottery. He wrote parts of several books on the subject and left his collection to the Fitzwilliam Museum at Cambridge. His extensive collection was considered one of the finest collections of slipware in the world. Glaisher also collected valentines and children's books; these also were donated to the Fitzwilliam Museum.

Glaisher never married. He died in his college room at Cambridge. None of the referenced works cite the actual cause of death, but state that he was a robust man who loved hiking and bicycle riding, yet suffered from failing health in his last few years.

A nearside lunar crater at latitude 13°.2 N, longitude 49°.5 E was named in the 1860s to honor the father, James Glaisher, based on a lunar map by Dr. John Lee. James Whitbread Lee Glaisher was named in part to honor Dr. John Lee and Samuel Charles Whitbread, who were friends and fellow founders with James Glaisher of the British Meteorological Society (now known as the Royal Meteorological Society), in 1850.

Robert A. Garfinkle

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Godefridus Wendelinus

➔ **Wendelen, Govaart [Gottfried, Godefried]**

Godin, Louis

Born **Paris, France, 28 February 1704**
Died **Cádiz, Spain, 11 September 1760**

The Frenchman Louis Godin is part of the history of astronomy mainly for two activities conducted outside of France. First, he participated in a geodesic expedition that measured the degree in lands of the Viceroyalty of Peru; second, he was director of the Academy of the Marine Guard of the Kingdom of Spain, in Cádiz, and of its astronomical observatory.

The son of François Godin and Elisabeth Charron, Godin studied astronomy with **Joseph Delisle**, at the Royal College of Paris. He was selected as a member of the Academy of Sciences without having published anything in 1725. His astronomical and literary career started in the academy by publishing minor works until the institution made him editor of the previously unedited *Mémoires de l'Académie des sciences*, corresponding to the years 1666–1730, which comprise seven volumes. From 1730, up to the volume for 1735, Godin was also in charge of editing of the *Connaissance des temps*, the official French astronomical ephemerides.

The academy chose Godin as the leader of the expedition to measure three meridian degrees in lands of Ecuador more because of his prestige as an organizer and scholar than as an astronomer. His persistence was to bring the journey to pass. With Godin at the head of the expedition and with members that included **Pierre Bouguer**, **Charles de la Condamine**, and Joseph Jussieu, along with draftsmen and helpers, the Kingdom of Spain added the sailors Jorge Juan and Antonio de Ulloa.

The tensions within the expedition led Godin to have serious arguments with Bouguer and La Condamine. Helped by the Spaniards, Godin took the measurements on his own, duplicated by the French explorers. The Spanish publication of the data, *Astronomical and physical observations taken in the Kingdoms of Peru by order of S.M.* (Madrid, 1748), signed by Juan and Ulloa, without doubt collected the most important astronomical work of Godin and illustrates his guidance to the young Spanish sailors, who returned to Spain in 1745 having become observers and mathematical experts.

Because of unknown circumstances, Godin decided to stay in Peru upon his companions' return. In 1743 he accepted the post of head of the mathematics department at the University of Lima, replacing Pedro de Peralta. On 13 October 1745 he was expelled from the Academy of Sciences and replaced by **César Cassini de Thury**. In Lima, Godin did little. He did not have to teach, like previous professors had, due to a lack of students. He collaborated with the Gaceta of Lima and contributed the plans for rebuilding the city after the earthquake on 26 October 1746. Still in Lima, on 29 August 1747, Godin was named (at the behest of Jorge Juan) director of the Marine Guard Academy in Cádiz, Spain. He arrived in Europe in 1751, by way of Lisbon and Paris, where he spent a year trying to arrange his reinstatement into the academy, which he finally accomplished in 1756.

Godin arrived in Cádiz during the summer of 1753 to take charge as director of the academy and the newly created Marine Observatory. On 26 October 1753, he observed a partial solar eclipse and used the observations to verify the geographic coordinates of the observatory. At the same time, he participated in the "friendly literary assembly," a gathering of sailors, doctors, and learned people, organized by Jorge Juan.

Between 1 December 1755 and 10 January 1757, Godin was in Paris, fixing his affairs with the Academy. He then returned to Cádiz, where he became gravely ill. This situation, which caused him to fear for his life, continued until the beginning of the summer of 1759. Godin was able to conduct few astronomical projects before his death.

Godin observed comet 1P/Halley in April and May of 1759, prepared a history of the Cádiz Observatory, and did various works for a *Celestial History of the 18th Century*, which remain unpublished in his personal documents. The subsequent story of those documents is complex. The Spanish Navy claimed them, and, at least part of them, were sent to France, where they were dispersed.

In agreement with his troubled biography, Godin's astronomical publications were scarce, most of them in the *Mémoires de l'Académie de sciences*, which were written before his voyage to America in 1734. His true contribution to astronomy was, without a doubt, the mark he left in the work by Juan and Ulloa, which was the first complete description to be published on the methods used to measure 3° of longitude in the Equator and to correct observations for atmospheric refraction, and which included the methods to determine the differences in length by using sound.

Antonio E. Ten
Translated by: *Claudia Netz*

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Godwin, Francis

Flourished **England, *circa* 1566–1633**

English Bishop Francis Godwin posthumously inspired the latter Renaissance with his tale of *in situ* "space exploration": *The Man in the Moone* (1638).

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Gökmen, Mehmed Fatin

Born **1877**
Died **Istanbul, (Turkey), 6 December, 1955**

Fatin Gökmen is known for his reinvigoration of astronomical education in 20th-century Turkey. He was the founder and first director of the Kandilli Observatory in Istanbul, and his contributions include astronomical work on observation, the calendar, and instruments.

Fatin – "Gökmen" was added in 1936, after the foundation of the Turkish state – came from the district of Akseki in Antalya. His father, Qadi Abdulgaffar Efendi, was a traditional Islamic scholar, and Fatin Gökmen's early schooling was in the *madrasa* of his native town. He then moved to Istanbul where he learned classical astronomy and the methods of calendar preparation from the last Ottoman head-astronomer, Hüseyin Hilmi Efendi. He also worked in the famous Sultan Selîm time-keeping Institute (*muvakkithane*). Fatin Gökmen, encouraged by the Turkish mathematician **Salih Zeki**, pursued his higher education in the fields of astronomy and mathematics in the Ottoman University's Faculty of Sciences (Dârülfünûn), which opened on 31 August 1900. After 3 years, he graduated from that faculty with the first rank. Fatin subsequently taught mathematics in various high schools, and was eventually appointed in 1909 as a lecturer in astronomy and probability at the Faculty of Sciences of the Ottoman University. He continued to lecture there until he resigned in 1933, as a consequence of the ongoing reform movement.

Fatin Gökmen was a key figure in facilitating the emergence of the modern astronomical observatory in Turkey. The Imperial Observatory, established in Istanbul in 1867 under the directorship of A. Coumbary, was mainly a meteorological center. With the assistance of Salih Zeki, Fatin Gökmen was appointed director of this observatory, and he was also given the task of establishing a new observatory. On 4 September 1910 he began work on setting up such a facility, which was to become the Kandilli Observatory. Fatin Gökmen's initial work at the Kandilli Observatory was publishing meteorology bulletins in 1911/1912. His work later became more astronomically oriented and continued until his retirement in 1943.

Fatin Gökmen first wrote on astronomy for university lectures and was influenced by the analytical methods of the French astronomer **Henri Andoyer**. This revealed itself particularly in Fatin's work on positional astronomy entitled *Vazʿiyyāt ve vazʿiyyāta ʿāid mesāil-i umūmiyya*. In 1927, he published his work entitled *Mathematical Astronomy and the Double-false Theory*, compiled from his lectures at the university. His most important essay is on the determination and calculation of the total solar eclipse. Fatin approached the solar eclipse from an analytical perspective and, using geometry, explained the difficulties he encountered with his calculations. Using Andoyer's methods, he analyzed the solar eclipse of 16 June 1936, and his results were published by the Kandilli Observatory as the *L'eclipse totale du soleil du 19 Juin 1936*.

Besides being an astronomer, Fatin Gökmen also did work in the history of astronomy, particularly regarding observational instruments. He pursued important research on the subjects of astronomy and the calendar among premodern Turks as a contribution to The Society for the Investigation of Turkish History. In his work entitled *L'astronomie et le calendrier chez les Turcs* (The astronomy and the calendar of the [early] Turks), he benefited from studying *Zīj-i īlkhānī* of the great Islamic astronomer **Naṣīr al-Dīn al-Ṭūsī**. As a result of this study, Fatin concluded that the early Turks had made use of "Hellenic–Chaldean" astronomy, *i. e.*, the geocentric astronomy of **Ptolemy**; this was in contrast to the conventional view that they had followed Chinese astronomy.

As for Fatin's historical work on observational instruments, he made original contributions in his studies of the quadrant, which he published in his *Rubuʿtahtası nazariyatı ve tersimi* (The quadrant: its theory and design; Istanbul, 1948). In addition to explaining the function of this instrument, he also shed light on the Turkish contribution to it and its transmission to modern times. At the end of the work, Fatin included a glossary of astronomical terms in Turkish and French. In this way he contributed to building a bridge between the old and the new astronomy.

Fatin Gökmen also conceived of using a particular quadrant (the *Rubʿal-muqanṭarāṭ*) to make a table of the minimum and maximum values of the variations of the azimuth and the hour angle (up to ±3°) for a certain latitude. He further used the quadrant for finding the precision level required in geomagnetism, maps, and other related items as well as for determining the amount of refraction of light and for solving trigonometric problems.

Finally, we should mention that Fatin Gökmen made important contributions to the establishment and development of modern meteorology, geophysics, and seismology in Turkey.

Mustafa Kaçar

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Goldberg, Leo

Born **Brooklyn, New York, USA, 26 January 1913**
Died **Tucson, Arizona, USA, 1 November 1987**

American astrophysicist Leo Goldberg contributed significantly to our understanding of the physics of gaseous nebulae, stellar abundances, and the physics of stellar mass loss, chromospheres, and coronae. Born to Russian–Polish immigrant parents, Goldberg was an orphan at nine, but with financial help from an interested businessman, he was able to attend Harvard University receiving a BS in 1934, an AM in 1937, and a Ph.D. in astrophysics in 1938 for work with **Donald Menzel** on the quantum mechanics of astrophysically interesting atoms.

Goldberg at that time also analyzed the spectra of a number of O and B stars, finding that it was necessary to introduce a new parameter called microturbulence (representing convection on length scales smaller than the photon mean free path) into the analysis. He continued to develop this method over several decades to measure, for instance, how convection varies with depth in the atmospheres of stars.

After a brief period (1938–1941) as a research fellow at Harvard University, Goldberg became a research associate at the University of Michigan and McMath–Hulbert Observatory, moving upward to assistant and then full professor, and serving as chair of the department and director of the observatory from 1946 to 1960. He was Higgins Professor of Astronomy at Harvard University (1960–1973), department chair (1966–1971), and director of the Harvard College Observatory (1966–1971) in succession to Menzel. He moved to Kitt Peak National Observatory as director in 1971, retiring in 1977.

During the war years, Goldberg and his student **Lawrence Aller** wrote a well-known and frequently reprinted introduction to astrophysics, *Atoms, Stars, and Nebulae*. At the University of Michigan, he, Aller, and **Edith Muller** reanalyzed the spectrum of the Sun using newly available atomic data; their compilation of solar abundances remained the standard for more than 20 years after the 1960 publication.

Goldberg had also been involved in the development of new infrared detectors at the University of Michigan. Upon returning to Harvard he also became interested in the possibilities of observation from space, particularly in the ultraviolet, where solar abundances could be measured in both the photosphere and the chromosphere using ions not observable from the ground. Detectors developed partly under his leadership flew on rockets from 1964, on Orbiting Solar Observatories IV and VI, and on Skylab. A parallel laboratory effort with William H. Parkinson and Edmond M. Reeves determined atomic properties and transition probabilities for a number of highly ionized atoms found in stellar winds, coronae, and chromospheres.

Taking advantage of the Kitt Peak telescopes during his directorship, Goldberg began work on physical processes in red giant stars, including mass motions, chromospheres, and measurements of angular diameter and limb darkening. He published his last paper, on Betelgeuse, only 2 years before his death.

Goldberg had a lifelong interest in international relations within science, chairing the United States committee for the International Astronomical Union [IAU] at the height of the Cold War. He was vice president of the IAU (1958–1964), president (1973–1976), and founder and first president (1964–1967) of its Commission on Astronomical Observations from Outside the Terrestrial Atmosphere (now High Energy and Space Astrophysics).

Another long-term interest was the unity of the American astronomical community and the provision of first-rate observing facilities for all astronomers, independent of their affiliation. Thus Goldberg was part of the organizing committee of the Association of Universities for Research in Astronomy [AURA] (1956–1957; board member, 1966–1971) that built and operates Kitt Peak and the other national optical observatories. Moreover, he was an early member of the board of Associated Universities (1957–1966), which operates additional national facilities.

Goldberg served as vice president (1959–1961) and president (1964–1966) of the American Astronomical Society. He served on advisory boards for the National Academy of Sciences, Air Force, National Aeronautics and Space Administration, and Department of Defense, receiving medals from the latter two. He edited *Annual Reviews of Astronomy and Astrophysics* from its inception in 1961 through 1973.

Léo Houziaux

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Goldschmidt, Hermann Chaim Meyer

Born **Frankfurt am Main, (Germany), 17 June 1802**
Died **Fontainebleau, Seine-et-Marne, France, 30 August 1866**

Hermann Goldschmidt, the son of Meyer Salomon Goldschmidt and Hindle Cassel, was most noted for his discovery of 14 asteroids.

Between 1820 and 1846, Goldschmidt studied painting in Munich under Schnorr von Cornelius and lived in the Netherlands, Paris, and Rome, finally settling permanently in Paris. Here he achieved some success as a painter, perhaps through the efforts of his friend **Alexander von Humboldt**. In 1847 Goldschmidt was commissioned to copy portrait paintings in foreign collections for King Louis-Philippe's expanded collection of art at Versailles, and his *Romeo and Juliet* was purchased by the state from the Paris Salon of 1857. Goldschmidt married Adelaide Pierette Moreau in 1861 and had two children, Hélène and Josephine.

Goldschmidt's painting career helped subsidize his passion for astronomy as an amateur. From a rooftop room in the Café Procope, Paris, Goldschmidt made his first discovery of a minor planet, (21) Lutetia, in 1852. Over the next 14 years his more famous contemporaries, including **Urbain Le Verrier** and **Dominique Arago**, named his 14 asteroid discoveries. Goldschmidt was involved in a debate over the system of nomenclature for minor planets in the pages of *Astronomische Nachrichten*, and was one of the first to have one of his discoveries named for a nonmythological figure, (45) Eugenia, the Empress of France.

Goldschmidt was an assiduous observer of variable stars, comets, and nebulae, and traveled to Spain to observe the total solar eclipse of July 1860. Among his many reports of astronomical findings, his only notable erroneous submission was a mistaken sighting of a ninth moon of Saturn, not in fact discovered until 1898.

For his asteroid discoveries and other astronomical contributions, the French Academy of Science awarded Goldschmidt the prestigious Lalande Astronomical Prize eight times, the Cross of the Legion of Honor was conferred upon him in 1857, and in 1862 he was awarded an annual pension for his astronomical work. The Royal Astronomical Society conferred its Gold Medal on Goldschmidt in 1861.

Alun Ward

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Goldsmid, Johann

➔ **Fabricius, Johann**

Goodacre, Walter

Born **Loughborough, Leicestershire, England, 1856**
Died **Bournemouth, Dorset, England, 1 May 1938**

Walter Goodacre was the preeminent British selenographer of the early 20th century. His monograph on the Moon was considered a primary resource for selenographers for several decades after its publication.

Goodacre was born at Loughborough, but in 1863 the family moved to London, where his father founded a carpet manufacturing business. Walter Goodacre established a branch of the family business in India and visited there frequently for 15 years. He succeeded his father as head of the firm in London, remaining in that position until his retirement in 1929.

Attracted to astronomy as a boy, for a time Goodacre directed the Lunar Section of the Liverpool Astronomical Society. As a founding member of the British Astronomical Association [BAA], following the death of **Thomas Elger**, Goodacre was appointed to the directorship of the BAA Lunar Section, a post he held until 1 year before his death. He served as president of the BAA from 1922 to 1924, and was a lifetime fellow of the Royal Astronomical Society.

In 1910, Goodacre issued a 77-in.-diameter lunar map (scale 1:1,800,000) in 25 sections, the first such map to employ rectangular coordinates or direction cosines. Principally based on photographs, it employed 1,400 positions measured from negatives obtained at the Paris and Yerkes observatories by **Samuel Saunder**, a mathematics master at Wellington College. Although inferior in aesthetic appeal to the earlier maps of **Johann von Mädler** and **Johann Schmidt**, it was far superior in positional accuracy. Goodacre's map served as the basis of the first detailed lunar contour map, constructed in 1934 by the German selenographer Helmut Ritter.

In 1931, Goodacre privately published a book containing a reduced copy of his map and an exhaustive description of the named formations under the title *The Moon with a Description of Its Surface Features*. Unfortunately, the press run was a short one, and the volume is now exceedingly rare, commanding exorbitant prices by collectors. For his monograph, Goodacre reduced the scale of his 1910 map from 77 in. to 60 in., enhanced it with additional detail, and then divided it into 25 sections to facilitate his discussion of various lunar features. His 41-page introduction to the book is a useful introduction to selenography and includes a discussion of the classification of lunar structures supplemented by six plates containing 36 diagrams and one photograph. The discussion includes historical observers as well as more contemporary authorities like **William Pickering**.

Goodacre's approach to selenography was pure Baconian empiricism. He wrote:

> One of the chief sources of pleasure to the lunar observer is to discover and record, at some time or other, details not on any of the maps. It also follows that in the future when a map is produced which shows all the detail visible in our telescopes, then the task of selenography will be completed.

In 1928, Goodacre endowed a fund to the BAA for the recognition of outstanding members. The Walter Goodacre Medal and Gift is considered the association's highest honor; it has been awarded approximately biennially since 1930. In 1883, Goodacre married Frances Elizabeth Evison; their marriage was blessed with two children, though Francis died in 1910.

Thomas A. Dobbins

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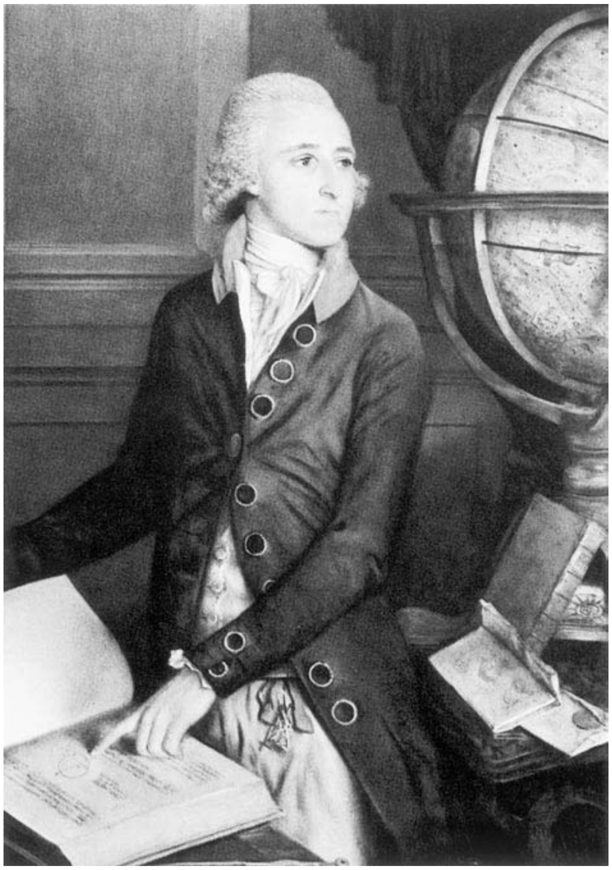
Goodricke, John

Born **Groningen, the Netherlands, 17 September 1764**
Died **York, England, 20 April 1786**

John Goodricke was a pioneer investigator of variable stars. Goodricke's family moved to England, where he attended the Braidwood Academy, Great Britain's first formal school for deaf children. According to an



1815 report, “he lost his hearing by a fever when an infant, and was consequently dumb: but having in part conquered this disadvantage by the assistance of Mr. Braidwood, he made surprising proficiency, becoming a very tolerable classic, and an excellent mathematician.” Goodricke then entered the Warrington Academy, a dissenting academy. His family settled in York. It is there that his first entry in an “astronomical journal” is dated 16 November 1781. The Goodrickes’ neighbor, Nathaniel Pigott, was an amateur astronomer, and Pigott’s son, Edward, was also enthusiastic about astronomy. **Edward Pigott**’s personal correspondence indicated that he had a challenge communicating with his deaf friend, although he welcomed the company of a like-minded enthusiast. Communicating side by side in the dark during observations was especially difficult. Pigott, 11 years older than Goodricke, was in many ways his mentor. He encouraged Goodricke to watch for variable stars and introduced him to the variability of Algol (β Persei). Both had become fascinated with the name “Algol” and romanticized its meanings to the ancient world.

During this early period, Goodricke used opera glasses and a small perspective glass with a magnification of only 10× or 12× to observe comets and stars, including **William Herschel**’s recent discovery of a “comet” (later to be named the planet Uranus). Goodricke finally acquired an achromatic telescope with greater magnification, modified it with crosswires, and continued to study Uranus.

In his astronomical journal, Goodricke’s entry for 12 November 1782 expresses astonishment at having found a large drop in the brightness of Algol. Only a week before, he had observed Algol as second magnitude. Goodricke was struck by the suddenness of this variation. Following many more observations, he contacted the Royal Society through Edward Pigott. William Herschel himself took the report seriously, then made his own observations and reported them on 8 May to the Royal Society. From that time, Goodricke and Herschel corresponded regularly. Among the correspondence is a draft of a letter written by Goodricke to Herschel on 2 September 1784, dealing with the prediction of an Algol brightness minimum. On this subject, Goodricke also wrote to Anthony Shepherd, Plumian Professor at Cambridge, a letter subsequently read to the Royal Society on 12 May 1783 and published in the *Philosophical Transactions* as “A series of observations on, and a discovery of, the period of variation of light of the bright star in the head of Medusa, called Algol.” Goodricke’s estimate of the period of Algol was 2 days, 20 h, 45 min. This differs only a few minutes from the modern value.

Even with today’s sophisticated telescopes and the statistical analyses of irregularities in the light curves of the stars, this observation of Algol is difficult. Goodricke also conjectured on the cause of the changes in brightness, noting that Algol appeared to have a companion, and that the system eclipsed itself at regular intervals. With his letter to the Royal Society, Goodricke included a table of his observations that contained the dates, times, and number of revolutions. The speculation of a periodic eclipse by a large, dark body remained unproven for nearly a century until the German astronomer **Hermann Vogel** used spectrographic analysis to confirm that Algol was indeed a binary star.

Goodricke’s discovery led to great interest in Algol’s periodicity among other astronomers who sent confirmations of the amateur’s observations to the Royal Society. Some used Goodricke’s paper to argue for the existence of planets outside the Solar System. At the age of 19, Goodricke received Britain’s highest scientific honor, the Royal Society’s Copley Medal.

In August 1784, Goodricke began to study Lyra, Capricorn, and Aquarius and compare his measurements with the data found in **John Flamsteed**’s *Atlas*. By September, he had concluded that β Lyrae also was a variable star whose light curve could be explained by eclipses occurring at intervals of a little more than twelve days.

A month later, Goodricke identified δ Cephei as a variable star system. He noticed that it behaved differently from Algol, brightening much faster than it faded, in a way not easily explained by eclipses. He wrote to **Nevil Maskelyne** and described the strange quality in the fluctuations of brightness in δ Cephei. In this letter, published in *Philosophical Transactions* in 1785, Goodricke again credited the assistance of Pigott.

News of the young deaf astronomer’s findings made an impact on the British scientific community. Sadly, he would experience few of their accolades. Two weeks after he was elected a fellow of the Royal Society, John Goodricke died after exposure to the cold night air while making his observations. Minor planet (3116) Goodricke is named in his honor.

Harry G. Lang

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Gopčević, Spiridion

➤ **Brenner, Leo**

Gore, John Ellard

Born **Athlone, Co. Westmeath, Ireland, 1 June 1845**
Died **Dublin, Ireland, 22 July 1910**

As a skilled amateur astronomer and prolific writer, John Gore made significant contributions to variable-star and binary-star astronomy, and to the popularization of astronomy and cosmology. He was among the first to estimate the size of red giant and white dwarf stars.

Gore was the oldest son of John Ribton Gore (1820–1894), Archdeacon of Achonry and his wife Frances (*née* Ellard). He was educated privately and entered Trinity College Dublin in 1863. Gore graduated in 1865 with a diploma in engineering and a special certificate of merit, standing first in his class in both years. After working as a railway engineer in Ireland for more than 2 years, he joined the Indian government public works department in 1869 and worked on the construction of the Sirhind canal in Punjab.

Under the clear Indian skies Gore began to observe double and variable stars with achromatic telescopes of 3-in. and 3.9-in. aperture. The results of this work were published in 1877 as *Southern Stellar Objects for Small Telescopes* and described objects between the celestial equator and −55° declination. Observing with the naked eye at an altitude of 6,000 ft in the Himalayas, Gore was able to detect previously unrecorded rifts and faint extensions of the Milky Way. While Gore was in India, he was elected a member of the Royal Irish Academy on 12 April 1875.

Gore returned to Ireland on 2 years' furlough in 1877 but never returned to India. He retired from the Indian service in 1879 and drew a pension for the rest of his life. Gore resided at Dromard, near Ballysadare, where his father had been appointed rector in 1867. After the death of his father in 1894, Gore moved to Dublin where he lived in lodgings for the rest of his life.

While there is no evidence that Gore studied astronomy as a student at Trinity College, he would have had ample opportunities to visit the observatory of **Edward Cooper** at Markree Castle Observatory in County Sligo. Markree Castle was only about 10 miles from Dromard. It seems very likely that Gore would have known and consulted August William Doberck (1852–1941), director of Markree Observatory from 1874 to 1883, and his successor **Albert Marth** (1828–1897). However, for his own observations, Gore never used large telescopes but relied on his naked eyes or on a pair of 6 × 50 binoculars.

In January 1884, Gore presented to the Royal Irish Academy his first major paper entitled *A Catalogue of Known Variable Stars with Notes and Observations.* The catalog contained 190 entries, which were increased to 243 in the revised edition published 4 years later. In 1884, he also presented to the academy *A Catalogue of Suspected Variable Stars with Supplementary Notes*; this contained details of 736 stars. Between 1884 and 1890, Gore discovered four variable stars: W Cygni, S Sagittae, U Orionis, and X Herculis. From 1890 to 1899 he was director of the Variable Star Section of the British Astronomical Association. W.W. Bryant, in his *History of Astronomy* (1907), named Gore as one of the three leading observers of variable stars in Britain and Ireland.

From 1879 onwards Gore devoted much time and energy to calculating the orbits of binary star systems. In 1890 he presented to the academy *A Catalogue of binary stars for which orbits have been computed with notes,* containing details of 59 binary systems.

Gore may have been among the first to realize the great range in size of stars. In 1894, his friend, the amateur astronomer **William Monck** of Dublin, suggested that there were probably two distinct classes of yellow stars – one being dull and near, the other being bright and remote. This clue to the existence of dwarf and giant stars was taken up by Gore. Using heliometer parallax measurements by **William Elkins**, Gore estimated that the red star Arcturus had a diameter about 80 times that of the Sun. Although Arcturus's size was overestimated because of inaccurate data, Gore's argument was sound.

In 1905, Gore attempted to estimate the density of Sirius B, which was known to have a mass equal to the Sun's mass. He calculated that the satellite was about 1,000 times fainter than the Sun. Its faintness could be due to either its small size or its low surface luminosity. If Gore assumed its surface luminosity was the same as the Sun, he found it would have a density over 44,000 times the density of water, which he thought "entirely out of the question." The modern value of the mean density of Sirius B is in the region of three million times the density of water.

Between 1877 and 1909, Gore published 12 popular books on astronomy. In 1894 he published his translation of **Camille Flammarion**'s *Astronomie Populaire*(Popular Astronomy), which received very favorable reviews. The same year *The Worlds of Space* appeared. This collection of miscellaneous papers and articles, which included some chapters on life on other worlds, was criticized by H. G. Wells for not being more speculative. Gore contributed to the astronomy volume of the *Concise Knowledge Library* (1898) in collaboration with **Agnes Clerke** and **Alfred Fowler**. In his *The Visible Universe*, Gore speculated on the origin and construction of the heavens, analyzing a number of cosmologies including those of **Thomas Wright, Immanuel Kant**, **Johann Lambert**, **William Herschel**, **Richard Proctor**, and others. Gore concluded that our Universe (Galaxy) is limited and cannot contain an infinite number of stars. His reasoning was similar to that of **Jean Loys de Chéseaux** and **Heinrich Olbers** with respect to the brightness of the night sky, but Gore concluded that there might well be other "external universes" or galaxies that were invisible.

Gore was a regular contributor to *Monthly Notices of the Royal Astronomical Society*, *The Observatory*, and the *Journal of the British Astronomical Association*. He was elected a fellow of the Royal Astronomical Society in 1878 and served on the councils of the Royal Irish Academy and the Royal Dublin Society. Gore was a leading member of the Liverpool Astronomical Society and was chosen as a vice president of the British Astronomical Association on its foundation. He was an honorary member of the Welsh Astronomical Society, a fellow of the Association Astronomique de France, and a corresponding fellow of the Royal Astronomical Society of Canada.

Gore was described as a grave, quiet man with few friends but very much liked by those who knew him. He was noted for his quiet wisdom and gracious courtesy. He never married, and, when failing sight restricted his astronomical activities, he presented his library to the Royal Irish Academy. Gore died after being struck by a horse-drawn cab.

Ian Elliott

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Gorton, Sandford

Born **England, 1823**
Died **Clapton, (London), England, 14 February 1879**

Founding editor and publisher of the *Astronomical Register*, Sandford Gorton was an active member of the Royal Astronomical Society [RAS] and attended its meetings regularly. He realized that there was no medium for amateurs like him to compare observations and exchange notes on techniques, topics that were increasingly excluded from the content RAS meetings. Also, disturbed that the minutes of RAS meetings published in the *Monthly Notices of the Royal Astronomical Society* failed to report the essential details of arguments, and were instead dry and limited in content to essentially the transactions taken in the meeting, Gorton resolved to cure such ailments by publishing a new journal, *The Astronomical Register*.

This is how Gorton described it in the first issue in January 1863, "the present attempt [will] introduce a sort of astronomical 'Notes and Queries,' a medium of communication for amateurs and others …" It was his intent to include a monthly "table of occurrences" or short-term ephemerides, to save time for the "nonprofessional observers." A printer by trade, Gorton wrote and printed the entire first volume himself. However, he was unable to sustain the burden of printing as the *Register* grew in size and circulation. Gorton did, however, retain complete editorial control for a number of years, and the results were remarkable. The faithful reporting of the RAS meetings by Gorton and others who followed him as *Register* editor reveal much of the dynamics of the professionalization of the RAS over the next two decades. After his death, *The Astronomical Register* continued until 1886. By then, it had, in effect, been supplanted by another publication, *The Observatory*, created by the RAS professional astronomers in the year of Gorton's death to serve many of the same functions which Gorton's *Astronomical Register* had been intended to serve.

Thomas R. Williams

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Gothard, Jenõ [Eugen] von

Born **Herény, (Hungary), 31 May 1857**
Died **Herény, (Hungary), 29 May 1909**

One of the first astrophysicists in Hungary, Jenõ von Gothard was a respected early contributor to the evolution of astrophysics, especially in the practical aspects of instrument development and application. As the oldest son of István and Erzsébet (*née* Brunner) von Gothard, Jenõ von Gothard was born into a privileged family. Both his father and his grandfather were interested in avocational science. After completing the curriculum at the gymnasium in Szombathely in 1875, Gothard studied at the Polytechnische-Hochschule in Vienna, earning a diploma of mechanical engineering in 1879. While in Vienna, he also studied geodesy and astronomy, gaining experience in the institute's astronomical observatory. As was the convention in those days, Gothard then visited universities in Western Europe before he settled on a career. He was accompanied, for at least part of that trip, by his friend **Miklós Konkoly Thege** of Ógyalla, Hungary.

When Gothard eventually returned to his family estate at Herény, his intention was to build a physical laboratory. However, on being persuaded by Konkoly Thege, Gothard and his brother, Sándor (Alexander) von Gothard, built an astrophysical observatory at Herény (now suburb of Szombathely). The first observations from the observatory were made from the new dome in the autumn of 1881. After it was completed in 1882, the observatory was equipped with state-of-the-art instruments. Konkoly Thege donated the largest telescope to the new observatory, a Browning silver-on-glass 10.25-in. Newtonian reflector. After a few years of more general observing, the observatory program settled down to the development of photographic and spectrographic techniques and their exploitation in astronomy.

Gothard made pioneering studies on application of photographic technique in astronomy. He photographed the first extragalactic supernova, S Andromedae (SN 1885 A), within days of its independent discovery on 19 August 1885 by Countess Berta Dégenfeld-Schomburg at the nearby Kiskartal Observatory. He discovered the central star of the Ring Nebula (M57, a planetary nebula in Lyra) on a photographic plate in 1886. Gothard's comparison of the spectrum of Nova Aurigae 1892 with the spectra of several nebulae and other celestial objects obtained with the same quartz spectrograph allowed him to identify with certainty several bright lines that appeared both in the spectrum of the nova and in the nebulae, at times giving the nova spectrum the appearance of a Wolf–Rayet star. Similar studies conducted for Nova Persei (1901) with an objective prism, as well as the quartz spectrograph, showed the nova to be passing through several specific stages as it matured. On the basis of these observations Gothard was able to point out that during the nova eruption a gaseous envelope was apparently ejected from the star.

Gothard published his astrophysical observations mainly in *Astronomische Nachrichten* as well as in the *Memoirs of the Hungarian Academy of Sciences*. Translations of these articles were also published in *Astronomy and Astrophysics* and *Monthly Notices of the Royal Astronomical Society.*

Gothard published several books in Hungarian about modern observational methods in astronomy. He made several astronomical instruments in his workshop for other institutions, including a transit instrument for the Heidelberg Observatory and a spectrograph for the technical university in Vienna. His wedge photometer served as the model for the photometer marketed by the firm of Otto Töpfer, of Potsdam. Gothard also was a prolific inventor of instruments for photography, a field in which his contributions are recognized more highly than they are in astronomy.

In 1895, Gothard was appointed technical director of the Vasvármegye Electric Works, an electrical system then being developed in the county surrounding Szombathely. His duties in that position, which he prosecuted with great success for several years, made it increasingly difficult for him to pursue astrophysics to the extent he might have desired. His health began to fail in 1899, but Gothard deferred retirement from active employment until 1905, devoting the remainder of his life to travel and rest. He never married.

Gothard was elected a fellow of the Astronomische Gesellschaft (1881), and of the Royal Astronomical Society (1883), and a corresponding member of the Hungarian Academy of Sciences (1890). A crater on the Moon is named for him.

László Szabados

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Gould, Benjamin Apthorp

Born **Boston, Massachusetts, USA, 27 September 1824**
Died **Cambridge, Massachusetts, USA, 26 November 1896**

Benjamin Apthorp Gould founded the *Astronomical Journal*, copioneered with **Lewis Rutherfurd** the application of photography to astrometry (the determination of the positions of the stars and planets), headed the effort to use the first successful transatlantic telegraph cable to determine the longitude difference between Boston and Liverpool, and created the first comprehensive catalogs of Southern Hemisphere stars. Along the way, Gould was the first director of the Dudley Observatory in Albany, New York, one of the original members of the National Academy of Sciences established by the US Congress in 1863, and a founder and first director of the National Observatory at Córdoba, Argentina.

The eldest of four children born to Benjamin Apthorp Gould, Sr. and Lucretia Dana Goddard, Gould was precocious, reading aloud by age three, composing Latin odes by age five, and giving lectures on electricity by age 10. After primary schooling, he attended the Boston Latin School, graduating at age 16 and entering Harvard College. While studying the classics, Gould became interested in biology and astronomy, taking courses from astronomer **Benjamin Peirce**.

In 1844, Gould graduated from Harvard college at age 19 with a distinction in mathematics and physics, along with membership in Phi Beta Kappa. After teaching classical languages for a year at the Roxbury Latin School, he decided to pursue a career in science. Upon the advice of **Sears Walker**, a family friend and mathematical astronomer, Gould decided to spend time in Europe mastering modern languages and European scientific methods.

His 3-year trip from 1845 to 1848 became the defining event of Gould's life. Family connections provided him with letters of introduction to eminent scholars, with whom he established lifelong correspondence. He worked at the Royal Greenwich Observatory with Astronomer Royal **George Airy**, and at the Paris Observatory with **Dominique Arago** and **Jean Biot**. But Gould found his true intellectual home in Germany, where he worked with **Johann Encke** at the Berlin Observatory and studied mathematics at the University of Göttingen under the supervision of **Carl Gauss**. In 1848, armed with a new doctorate in astronomy and fluent in Spanish, French, and German, Gould meandered home *via* the observatory in Altona. There, he spent 4 months with **Heinrich Schumacher**, founder and editor of the *Astronomische Nachrichten*, then the foremost international astronomical research journal. It is still being published, though no longer so important.

Upon his return, Gould became depressed with the United States' lack of adequate research libraries and interest in learning foreign languages. He vowed to improve the state of astronomy at home. In 1849, with his own funds, Gould founded the *Astronomical Journal*, the first scholarly United States research journal of astronomy in the spirit of the *Astronomische Nachrichten* and in deliberate contrast to the short-lived popular monthly *Sidereal Messenger* (1846–1848) published by **Ormsby Mitchel** of the Cincinnati Observatory. So committed was Gould to his mission of improving American astronomy that in 1851, despite the struggling finances of the *Astronomical Journal*, he turned down an offer from Gauss of a professorship at Göttingen and its promise of becoming director of the Göttingen Observatory.

Meanwhile, through his former Harvard college mentor **Benjamin Peirce**, Gould had become part of the scientific Lazzaroni, a small group of American scientists who shared similar visions for improving the international standing of American scientific research. Among them was **Alexander Bache**, head of the United States Coast Survey. In 1852, Bache hired Gould to head the Coast Survey's telegraphic determination of longitudes, succeeding Walker who was terminally ill.

Gould remained with the Coast Survey for 15 years, while continuing to publish the *Astronomical Journal* and pursuing other astronomical work. Following his German mentors, his work focused on the positions and motions of heavenly bodies, emphasizing mathematical rigor and quantification of sources of error. In 1856, he analyzed the determination of the solar parallax made by four temporary observatories south of the Equator. In 1862, he collated a century of observations of the positions of 176 stars from different observatories into a single catalog, which became widely adopted. In 1866, Gould led the Coast Survey's effort to determine the longitude difference between the Royal Greenwich Observatory and the Harvard College Observatory using the first successful transatlantic telegraph cables. He also quantified observers' personal equations and extended Walker's work in measuring the velocity of telegraph signals.

In 1861, Gould married the former Mary Apthorp Quincy, fathering five children. She helped finance a private observatory near Cambridge, from which he made meridian observations of faint stars near the North Celestial Pole between 1864 and 1867. In 1866, Gould experimented with Rutherfurd in applying the new technology of photography to astrometry and using a micrometer to measure stellar positions on a photographic plate instead of at the telescope's eyepiece.

Gould also suffered notable failures. In 1855, he became an advisor to the fledgling Dudley Observatory in Albany, New York; his Coast Survey connection was helpful in providing the observatory with instruments and observers. The trustees agreed to bear the financial costs of the *Astronomical Journal*, so its headquarters were moved from Cambridge to Albany in 1857, followed by Gould himself in 1858 after he became the Observatory's first director. Pursuing his vision to establish a world-class German-style research Observatory, Gould traveled to Europe to order equipment. The trustees felt the observatory and its telescopes should be opened to the general public, however, which Gould refused. Annoyed by delays in the equipment and unforeseen expenses, the trustees accused Gould of arrogance and incompetence. The standoff degenerated into a vicious newspaper campaign, at the end of which Gould was forcibly ejected from the director's house in 1859.

This highly public controversy polarized the American astronomical community. Moreover, Gould failed both in 1859 and in 1866 to become director of the Harvard College Observatory. He alienated his former mentor Peirce, who became director of the Coast Survey after Bache's death, a circumstance that compelled Gould to quit his job of 15 years. Gould's unyielding and antagonistic behavior and his emotional peaks and valleys have led recent historians to speculate that Gould might have suffered from bipolar (manic-depressive) disorder.

The 43-year-old Gould's astronomical career thus seemed over in 1867, but a saving circumstance intervened. Gould had long been aware that there was no comprehensive precision catalog of Southern Hemisphere stars. In 1865, he had approached the Argentine government through its minister in Washington, to explore the possibility of founding a private observatory in Córdoba, a location free from both coastal hurricanes and earthquakes. Luckily for Gould, the minister was Domingo Fautino Sarmiento, a man zealous to improve his nation's intellectual attainment. Sarmiento offered to cover much of the expense if Gould would establish a national observatory for Argentina. By 1868, Sarmiento himself had become Argentina's president, and funds for a national observatory had been approved by the Argentine Congress.

In 1870, Gould left for Argentina with his wife and children. What he originally envisioned as a 3-year stint eventually stretched out to 15. Before the observatory's main instruments arrived, Gould and his assistants cataloged all of the naked-eye stars visible in the Southern Hemisphere. In so doing, they established the existence of Gould's belt of bright stars that intersected the plane of the Milky Way at an angle of 20°, leading Gould to conclude that our solar system was removed from the principal plane of the Milky Way. After the observatory's main instruments were installed, Gould and his staff measured the positions of 73,160 stars between −23° and −80° declination in his zone catalogs, and 32,448 in the more precise general catalog. These results were published as the *Resultados del Observatorio Nacional Argentino in Córdoba*, 15 volumes of which appeared between 1877 and Gould's death. This massive effort laid the groundwork for the authoritative *Córdoba Durchmusterung* catalog of southern stars, compiled by Gould's successors, **John Thome** and **Charles Perrine**.

Gould also acquired 1,099 photographic plates, which he measured after returning to the United States; those results were published posthumously. Gould participated in other observations, including the transit of Venus in 1882. Moreover, he organized the Argentine National Meteorological Office, establishing a nationwide system of 25 weather stations extending from the Andes to the Atlantic, and from the tropics to Tierra del Fuego.

Gould's life in Argentina was also marked with tragedy. His two eldest daughters drowned at a family birthday picnic, and his wife died in 1883 during a brief visit to the United States. Gould never fully recovered.

About a month after he returned to the United States for good in 1885, Gould was formally greeted by a banquet at the Hotel Vendôme in Boston that included scores of distinguished scientists, some of whom had formerly shunned him after the Dudley Observatory debacle. In 1886, Gould resumed publication of the *Astronomical Journal* (suspended since 1861 by the Civil War and Gould's time in Argentina). He died 2 hours after falling down the stairs of his home.

Trudy E. Bell

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Graham, George

Born **Hethersgill, (Cumbria), England, 1674**
Died **London, England, 16 November 1751**

George Graham, a British clockmaker, horologist, and preeminent instrument-maker of his time, is credited with the invention of the micrometer screw that allowed him to manufacture zenith sectors and calipers of unmatched accuracy. George Graham's father, also named George, died shortly after his son's birth. Raised by his uncle, Graham had no formal education in mechanics or astronomy and was apprenticed (1688–1695) to Henry Aske, a London clockmaker. The second Astronomer Royal, **Edmund Halley**, introduced Graham to the already successful London clockmaker Thomas Tompion. Graham later married Tompion's niece and became a business partner with Tompion from 1695 to 1713. He later succeeded to the business as heir by Tompion's will in 1713.

While he is reported to have manufactured only 200 clocks in his lifetime, Graham is credited with the invention of the deadbeat escapement in 1715, the mercury-compensated pendulum in 1722, and the cylinder escapement for watches, which greatly reduced case size needed for the mechanical movements, in 1725.

Among Graham's astronomical instruments was the zenith sector, an instrument designed to detect the annual parallax through measurements of the positions of one or more stars passing overhead of the observer. Graham manufactured one in 1725 for a prosperous amateur astronomer, **Samuel Molyneux**, of Kew. He followed this with an improved micrometer screw for a reflecting telescope in 1727. Graham also manufactured, for Halley, an 8-ft. quadrant, an instrument widely imitated.

Graham was also credited with the invention of the orrery, a clock-driven machine devised to represent the proper motion of the planets about the Sun. Others say that although Graham's orrery was one of the first, it was not the first instrument of this type. The device was named after the Earl of Orrery, for whom a copy of the instrument was manufactured by instrument-maker John Rowley. Graham manufactured several simple orreries, devices that showed the movement of the Earth about the Sun, and the Moon about the Earth. A grand orrery would show the movements of all of the planets known at the time about the Sun; it might also show day and night on the Earth, the seasons, and the phases of the Moon.

Graham provided monetary support and encouragement to John Harrison in 1728. Harrison's chronometers were the first timekeeping devices able to keep time on a ship within acceptable limits for measuring its position to within 1/2° after traveling from England to the West Indies. Graham may have manufactured some of the early chronograph movements for Harrison to the latter's specifications.

Graham's precision instruments were used in measurements that established the exact shape of the Earth and increased the precision of **Isaac Newton**'s calculations for the proportion of the Earth's axes. Graham was elected to the Royal Society in 1721, serving on its council the following year. He is buried in Westminster Abbey.

Donn R. Starkey

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Grassi, Horatio

Flourished **Italy, 1619**

Horatio Grassi was an Italian Jesuit and mathematician. He is best known for the malignant pamphlet he wrote against *Discorso delle comete* by **Galileo Galilei**, published in 1619, where Galilei argued that the comets are not sublunar fires because of their transparency and their small parallax. Grassi's pamphlet, entitled *Libra astronomica ac Philosophica*, was also published in 1619 under the name Lothario Sarsio Sigensano, an imperfect anagram of Horatio Grassio Saronensi. Galileo answered him with a still more virulent *Il saggiatore* in 1623.

Margherita Hack

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Gray, Stephen

Born **Canterbury, England, December 1666**
Died **London, England, 7 February 1736**

Stephen Gray was a dyer who corresponded with **John Flamsteed** on scientific matters. His early 18th-century sunspot observations record the Sun's recovery from the Maunder Minimum. Gray is better known for his experiments with electrical conduction and induction, for which he won both the first and second Copley Prizes of the Royal Society. Nonetheless, he died destitute.

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Greaves, John

Born **Colemore, Hampshire, England, 1602**
Died **London, England, 8 October 1652**

John Greaves was Savilian Professor of Astronomy at Oxford University and a noted antiquarian. He is especially notable for his interest in the astronomy of the ancients and in his efforts to preserve astronomical tables and manuscripts.

Greaves was the eldest son of the Reverend John Greaves, rector of Colemore in Hampshire, and the brother of Sir Edward Greaves (1608–1680), a physician, and of Thomas Greaves (1612–1676), an orientalist. He married in 1648 and died childless.

Greaves entered Balliol College, Oxford, in 1617, graduating with a BA in 1621. He was then elected to a fellowship at Merton College in 1624, receiving his MA in 1628. Greaves had great interest in natural philosophy and mathematics; learned oriental languages; and studied ancient Greek, Arabian, and Persian astronomers as well as **George Peurbach, Johann Müller** (Regiomontanus), **Nicolaus Copernicus**, **Tycho Brahe**, and **Johannes Kepler**. In 1630, while he held his fellowship at Merton, he was chosen professor of geometry in Gresham College, London. Greaves held the chair from 1630 to 1643.

In the late 1630s, Greaves traveled to Constantinople, Alexandria, and Cairo. He took measurements of several monuments and pyramids, and collected Greek, Arabic, and Persian manuscripts. Greaves returned to England in 1640, and was chosen to succeed **John Bainbridge** as Savilian Professor of Astronomy at Oxford, but was deposed from his position at Gresham on grounds of his absence. In 1642 he was appointed subwarden of Merton. On 30 October 1648, Greaves was expelled by parliamentary visitors from both his professorship and his fellowship on several grounds, including misappropriation of college property and favoritism in the appointment of subordinate college officers. At this time he lost a large part of his books and manuscripts, some of which were recovered by a friend. Greaves retired to London, where he married. Before his death he published several books and prepared several other manuscripts, some of which were published posthumously.

In 1645, Greaves proposed a reformation of the calendar by eliminating the bissextile day for the next 40 years, *i. e.*, the intercalary day inserted every 4 years in the Julian Calendar, but his scheme was not adopted. His principal contributions to astronomy consist in his efforts to collect and publish astronomical tables from Arabic and Persian sources. He also collected astronomical instruments that were left by will to the Savilian Library at Oxford and presented in 1659 to the Savilian Observatory by his brother Nicholas in his memory. A list of these instruments was published in 1697. The list includes one astrolabe, three quadrants (one of them a mural quadrant made by Elias Allen), two sextants, three telescopes (one of which was 15 ft. in length with three mirrors), a pendulum clock, a lined globe, and a cone cut to illustrate the formation of a parabola, hyperbola, and ellipse. The instruments were probably used in the observatory on the tower of the schools. During Greaves's tenure, then, Oxford was better equipped with instruments than Greenwich was. Among his several works, the following deserve mention: *Pyramidologia* (1646), *A Discourse of the Roman Foot and Denarius* (1647), *Anonymus Persa de Siglis Arabum et Persarum Astronomicis* (1649), *Astronomica quaedam ex traditione Shah Cholgii Persae, una cum Hypothesibus Planetarum* (1650), *Lemmata Archimedis e vetusto codice manuscripto Arabico* (1659), *An Account of the Longitude and Latitude of Constantinople and Rhodes* (1705), and *Miscellaneous Works* edited with biography by Thomas Birch (1737). Through the reports of his journeys, Greaves seems to have been well known to members of the Royal Society, the nucleus of which was formed by a group of scientists who began meeting at Gresham College in 1645. **Robert Hooke** mentions him in passing in two comments, at least one of which is simultaneously appreciative and critical.

Greaves maintained an extensive correspondence with the learned men of his day including Archbishop Ussher and William Harvey. His own contributions to geography and astronomy are minor, but he is emblematic of the scholarly interest of his day in mathematics, geography, and astronomy.

André Goddu

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Greaves, William Michael Herbert

Born **Barbados, 10 September 1897**
Died **Edinburgh, Scotland, 24 December 1955**

William Greaves was Astronomer Royal for Scotland and a Royal Astronomical Society president. He published the *Greenwich Colour Temperature Observations* in 1932 and 1952, based on his photographic photometry.

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Green, Charles

Born **Wentworth, Yorkshire, England, 26 December 1734**
Died **at sea, 29 January 1771**

Charles Green was an assistant at the Royal Greenwich Observatory who observed the transits of Venus in both 1761 and 1769. He was the youngest son of Joshua Green, a Yorkshire farmer. Charles was educated by his brother, the Reverend John Green, who ran a schools in Denmark Street, Soho, London, where Green later served as an assistant master. In 1760/1761, Green became assistant to the Astronomer Royal at the Royal Greenwich Observatory, serving under first **James Bradley** and later under **Nathaniel Bliss**. In March 1768, Green married Elizabeth Long and later that year sailed on James Cook's first voyage of discovery in order to observe the 1769 transit of Venus in Tahiti. He died on the journey home. Green was buried at sea at 11° 57′ S, 101° 45′ W.

Green's first professional experience of astronomy came when he was appointed as assistant to Bradley, who was renowned for his high observational standards. Green would have received a very thorough training under his tutorship. Together they observed the 1761 transit of Venus at Greenwich. Following Bradley's death in July 1762, Green continued as assistant to Bliss. Bliss was in poor health and spent most of his time away from the observatory. Consequently, most of the observational and calculation work of the observatory was carried out by Green.

In 1763, Green was appointed by the Board of Longitude to accompany **Nevil Maskelyne** on a voyage to Barbados to make longitude observations as part of the sea trial of John Harrison's watch H4. During the same voyage, Maskelyne tested the rival lunar distance method of finding longitude. Soon after Green arrived back in England in summer 1764, Bliss died and Green took sole charge of the Royal Greenwich Observatory until the following March when Maskelyne was appointed as fifth Astronomer Royal. Following some ill feeling between Maskelyne and Green, Green left the observatory to join the navy as a purser.

Some years later, Maskelyne, who respected Green's astronomical talents despite their personal disagreements, recommended him as the official astronomer on board Captain Cook's voyage on the *Endeavour,* the main purpose of which was to observe the 1769 transit of Venus. Green and Cook successfully observed the transit, and the results were published in the *Philosophical Transactions of the Royal Society* in 1771. After the ship left Tahiti, Cook went on to explore and chart New Zealand and parts of Australia. In his journal, Cook praised Green for his industry in making useful observations and calculations throughout the voyage and for teaching several of the petty officers to do likewise. Cook named an island off the coast of Queensland as Green Island in his honor.

Mary Croarken

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Green, Nathaniel Everett

Born **Bristol, England, 21 August 1823**
Died **Saint Albans, Hertfordshire, England, 10 November 1899**

Nathaniel Green drew artistic and yet highly accurate drawings of planets, especially Mars, Jupiter, and Saturn. He was the son of Benjamin Holder and Elizabeth (*née* Everett) Green. After receiving an education primarily from his uncle, Green entered a career in business, but in 1844 he found that art, specifically painting, was much more to his taste. In 1847, Green married Elizabeth Gould of Cork. As a professional artist, he made his living mainly as a successful art teacher. For a year he gave lessons to Queen Victoria and other members of the royal family. Green was also a successful author of practical manuals on art. He lived in then-rural west London, but also visited and painted in Palestine and Cannes, France, where in later years he spent winters for his wife's health as well as for the weather conducive to out-of-doors painting.

For most of his life Green was also an amateur astronomer. His main contributions were colored drawings of planets: a beautiful series of Mars for the close opposition in 1877 from Madeira. He also compiled a long series of drawings of Jupiter from 1859 to 1887. Both series were published in *Memoirs of the Royal Astronomical Society*. Green also made studies of the Moon and was active as a member of the Selenographical Society during its brief existence. Green's planetary and lunar drawings were of moderate resolution but carefully made. Responding to criticism that he preferred an artistic drawing to an accurate one, he replied, "I know no difference between the two." **James Keeler** apparently agreed, and was supportive of Green's resistance to inclusion of details at higher resolution than could likely exist in the eyepiece.

In his later years, Green was a leading figure in both the Royal Astronomical Society and the British Astronomical Association [BAA] and served as the first director of the BAA Saturn Section and as BAA president for the 1897/1898 session.

Richard Baum

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Greenstein, Jesse Leonard

Born **New York City, New York, USA, 15 October 1909**
Died **Duarte, California, USA, 21 October 2002**

American astrophysicist Jesse Greenstein discovered and clarified the properties of the largest sample of white dwarfs found up to that time. An outstanding administrator as well as scientist, he coordinated the most successful of the decadal reports, "Astrophysics for the 1970s."

Greenstein went to Harvard University at the early age of 16 and majored in astronomy, obtaining his BA in 1929. He had planned to go to the University of Oxford, but a health problem prevented that, and so he remained at Harvard University. His first research was on the temperature scale for O and B stars. **Cecilia Payne-Gaposchkin** had found that some O and B stars had abnormally low color temperatures in spite of showing high-excitation lines in their spectra. Greenstein showed that the mean color temperatures were lowest in the directions of the Milky Way. His explanation in terms of atmospheric effect was incorrect: He had found the general interstellar reddening caused by interstellar dust discoverd by **Robert Trumpler** very soon after. Harvard University conferred his MA in 1930.

Greenstein participated in his family's real estate and other businesses through the earliest years of the depression, simultaneously carrying out some astronomical research. He returned to Harvard University in 1934 and completed his Ph.D. in 1937.

Greenstein's thesis research concerned the interstellar medium and the associated absorption and reddening of starlight. He was particularly interested in the ratio of the extinction of the light from a star to the amount of reddening that the light experienced. Greenstein did calculations on Mie scattering by a distribution of small particles. He observed 38 highly reddened B stars by calibrated photographic spectrophotometry of objective-prism plates obtained with the 24-in. reflector at the Harvard Agassiz Station. The extinction law Greenstein found was $\lambda^{-0.7}$. He measured the general absorption in the region of each of the B stars and found the ratio of photographic absorption to color excess to be in the range four to six.

While at Harvard, Greenstein and **Fred Whipple** attempted to explain radio emissions from the Milky Way Galaxy, only recently discovered by **Karl Jansky**, as thermal radiation from dust grains. They concluded that the radio emissions could not be accounted for in that manner. However, Greenstein maintained his interest in radio astronomy and later strongly supported research in that area.

After graduating from Harvard University, Greenstein was fortunate to obtain a National Research Council Fellowship for 2 years. He chose to spend these at the Yerkes Observatory of the University of Chicago. Yerkes Observatory was then entering its great period under director **Otto Struve**, and its staff was preparing to use the McDonald Observatory in Texas, which was at that time under construction as a joint project of the universities of Chicago and Texas. When his fellowship ended in 1939, Greenstein was appointed to the University of Chicago faculty at Yerkes, where he remained until 1947. During most of that period he was a research associate at the McDonald Observatory.

At first, Greenstein worked principally on interstellar matter. With **Louis Henyey**, he studied the scattering of light by dust; an approximate formula that they developed for the particle scattering function later found applications in radiative transfer studies in astrophysics and atmospheric physics. In other collaborations with Henyey, Greenstein studied the diffuse galactic light by setting a photometer on apparently empty space between the stars. The two astronomers studied spectra of reflection nebulae and emission nebulae, and showed that H-α is widely distributed in the Milky Way, not just in bright nebulae.

Greenstein used the new 82-in. reflector at McDonald Observatory to study several stellar spectra. His first work was helping Struve to obtain coude spectra of τ Scorpii for **Albrecht Unsöld** to use at Kiel, spectra which became a testing ground for many subsequent developments in the analysis of stellar atmospheres. Greenstein analyzed the spectrum of the supergiant Canopus, the second brightest star in the sky, finding its composition to be normal. He observed υ Sagittarii, which he proved has a hydrogen-poor atmosphere. This was the first of many studies Greenstein made of abnormalities in stellar spectra.

During World War II, Greenstein remained at Yerkes Observatory, and was engaged with Henyey in optical design work for defense purposes. One noteworthy project was their design of a wide-angle camera for military aerial photography. The Henyey–Greenstein camera was later used by Donald Osterbrock and Stewart Sharpless to take several remarkable photographs of the Milky Way, the zodiacal light, the gegenschein, and the aurorae. The Milky Way really did look like an edge-on spiral with a dust lane!

Greenstein moved to California in 1948 when he was appointed professor (and chairman of the astronomy department) at the California Institute of Technology (Caltech), ending as the Lee A. Dubridge Professor of Astrophysics. He officially retired at the end of 1979. Greenstein was also a staff member of the Hale Observatories, and remained in that position from 1948 until 1980.

Greenstein was asked to go to Pasadena to help Caltech prepare for the operation of the Palomar Observatory, to gather the scientific staff for the Palomar Observatory, and to set up an outstanding astronomy graduate program at Caltech. He had to handle the complications of the joint operation by the Carnegie Institution of Washington and Caltech of the Mount Wilson and Palomar observatories. He was one of only two astronomers on the Caltech faculty, the other being **Fritz Zwicky**.

Soon after his arrival in California, Greenstein had an important collaboration with Leverett Davis. The polarization of starlight by the interstellar medium had just been discovered by **William Hiltner** and **John Hall**. Interstellar grains absorbed and reddened the light: To produce polarization required elongated grains, and the grains must be aligned over a large volume of space. Davis and Greenstein suggested that the grains contain small amounts of iron compounds and would be paramagnetic. The grains would be spinning rapidly because of collisions with hydrogen molecules in space. They suggested that an interstellar magnetic field of order 10^{-5} gauss must exist to align the grains, and the field lie along the spiral arms of the Galaxy. Paramagnetic spinning grains produce magnetic energy dissipation, which in turn leads to a torque, and this makes the grains spin around their shortest axis. Other astronomers studied other mechanisms for producing the grain alignment, but Davis and Greenstein's basic conclusions about the galactic magnetic field were correct.

Planetary nebulae had been observed to have a continuum in the visual spectral region. Recombination of hydrogen had been shown as not being the source of the continuum. Greenstein and **Thornton Page** considered the possibility that the capture continuum of the negative hydrogen ion might be the source, but that turned out to be too weak. The source was found by Greenstein and **Lyman Spitzer**, who showed that two-photon emission from the 2s state of hydrogen provided sufficient intensity. The 2s state was populated both by electron capture directly onto the 2s state and by electron collision transfer from the 2p state to the 2s state. The effect was to reduce the size of the Balmer discontinuity and reduce the calculated electron temperatures of the planetary nebulae.

After his move to California, Greenstein started very extensive studies of the chemical composition of stellar atmospheres. He continued these studies for more than 10 years and, with many collaborators, published about 60 papers in this field. Much of this work was related to studies of the origin of the elements, and complemented work on nuclear reaction cross sections being done at Caltech. Greenstein studied the isotope ratios ^{13}C/^{12}C and ^{3}He/^{4}He, and the nuclei ^{6}Li, ^{7}Li, ^{9}Be, and ^{98}Tc. The ^{13}C/^{12}C ratio in most stars seemed about the same as in the Sun. Comet C/1963 A1 (Ikeya) was observed, whose ^{13}C/^{12}C ratio was also about the solar value. The Li/H ratio was higher in young stars, and ^{3}He/^{4}He was high in some peculiar stars. Detailed interpretation of many of these observations proved more difficult than had been anticipated. An important paper with H. Larry Helfer and George Wallerstein determined hydrogen to metal ratios in two K type giant stars in globular clusters and in one high-velocity field star. The hydrogen to metal ratios were from 20 to 100 times the solar values. The ratios of other elements to iron were within a factor of five of solar values. Subsequent analyses of several other field giant stars indicated still more extreme metal deficiencies, up to factors of 800 less than the solar abundance. Some stars also showed peculiarities in the abundances of individual elements. Greenstein later commented that, after many years of work, the subject was clearly much more complicated than had been thought when he started.

White dwarf stars are faint objects, and in consequence they had been little studied in earlier years. The new equipment at the Palomar Observatory allowed Greenstein to initiate an extensive series of studies on white dwarf stars, their colors, spectra, compositions, magnetic fields, and evolution. A joint paper with Olin J. Eggen listed 166 white dwarf stars, mostly with new spectroscopic and photometric data. Greenstein developed a classification system for white dwarfs; his publications showed the large variations in the characteristics of white dwarfs. Some have hydrogen-rich and metal-poor surfaces, while others have helium-rich atmospheres. Some of his spectra showed unidentified very broad features.

Greenstein was interested in other kinds of faint stars, including subdwarfs and brown dwarfs. Working with **Lawrence Aller**, Greenstein analyzed three G-type subdwarfs and found metal deficiencies ranging from 20 to 100.

After the discovery, by Maarten Schmidt, of the large red shift $\delta\lambda/\lambda = 0.16$ of the quasar 3C273, Greenstein and Thomas Matthews confirmed this by showing that the previously unidentifiable lines in 3C48 could be explained by lines of common elements with a redshift of 0.367. Greenstein and Schmidt showed that the redshifts of quasars could not be gravitational, so that, unless new physics intervened, these sources must be very distant and very bright.

Greenstein was fortunate to be permitted to continue observing at the Palomar Observatory for some years after he retired. He had many collaborators, including James W. Liebert, J. Beverly Oke, Harry L. Shipman, and Edward M. Sion. Greenstein continued to make spectroscopic observations of white dwarfs and of many other stars.

Greenstein collaborated with a large number of astronomers in the compilation of a spectroscopic atlas of white dwarfs, which was published in 1993. This atlas showed in great detail the incredible variety of white dwarf spectra. It illustrated the refinements that had been made in the classification of these stars, as well as the little-understood peculiarities in individual spectra. Many white dwarfs had previously been classified as of type DC, the C indicating a continuous spectrum showing virtually no lines. Greenstein's later work reduced the apparent number of DC stars by using improved equipment at the Palomar Observatory. He demonstrated the presence of weak C_2 bands or weak He[I] lines in many of these stars. The star G 141-2 shows only a broad H-α line and apparently nothing else. The well-known white dwarf 40 Eri B could be observed in the ultraviolet and showed strong Lyman alpha and a strong line at 1391 Å which could possibly be Si[IV] or possibly molecular hydrogen. Among individual stars, GD 356 is unique; it has both H-α and H-β in emission, and both lines show Zeeman splitting corresponding to a magnetic field, if a dipole, of 20 megagauss. The magnetic star Grw +70° 8247 has an effective temperature of about 14,500 K and is a very small star, with a radius of only 0.0066 solar radius, making it one of the heaviest white dwarf stars known.

In other papers, Greenstein studied binary stars with both stars degenerate. In six pairs he found that the components were similar in luminosity and temperature; the white dwarfs are near-twins. There must be many more such pairs to be discovered.

Greenstein also studied binary stars that contain one normal star and one white dwarf. He concluded that duplicity has not changed the evolution of either the white dwarf or the main-sequence star. Each star evolves in isolation. These binaries are separated by many times the average separation of binaries with two main-sequence stars, so presumably there must be many more of these binaries to be discovered.

Greenstein obtained many spectra of other kinds of stars, including the star PC0025 +0047, which is an unusual M-type star and which he observed over a very wide range of wavelengths. It has the strongest water vapor bands and the strongest vanadium oxide bands in any known dwarf star. Its effective temperature must be as low as 1,900 K. It may be an old hydrogen-burning star with a mass of about 0.08 solar masses, or it may be a young brown dwarf.

Greenstein's total scientific output was prodigious, about 380 papers and articles in all. His later papers on white dwarfs list large numbers of these fascinating objects with strange characteristics, which should serve as a starting point for many future investigations.

Greenstein served on many national committees, starting soon after World War II ended. He was involved in the first grants committee for astronomy of the Office of Naval Research. He was on the first advisory committee of the National Science Foundation when it was considering its first astronomy grants. Greentein was chair of the National Academy of Sciences Astronomy Survey Committee and produced the second survey (1972) in what has become a series of decadal surveys. He was on National Aeronautics and Space Administration [NASA] committees, where he felt that he helped to bridge the gap between scientists and the NASA management.

Greenstein was a member of the Harvard Board of Overseers for 6 years. At Caltech, Greenstein served as the chairman of the faculty board. He resigned from heading astronomy at Caltech in 1972, but continued his observational work.

Greenstein received many honors, including election to the National Academy of Sciences, the Gold Medal of the Royal Astronomical Society, the Russell Lectureship of the American Astronomical Society, the Bruce Medal of the Astronomical Society of the Pacific, and an honorary D.Sc. from the University of Arizona in 1987.

Greenstein had two sons, one of whom, George (born: 1940), has been on the astronomy faculty at Amherst College since 1971. Peter (born: 1946) is active in music in California. Greenstein was predeceased by his wife Naomi, whom he met at Harvard and married in 1934.

Roy H. Garstang

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Greenwood, Nicholas

Flourished **England, 1689**

Nicholas Greenwood wrote a vernacular introduction to astronomy for seamen. Not much is known about Greenwood's education or personal history. From his major publication *Astronomia Anglicana* (London, 1689), it is apparent that Greenwood received a Latin-based education. He was a self-professed "professor of physic" and "student in astronomy and mathem." Greenwood also wrote at least one ephemeris for the year 1690.

Astronomia Anglicana was written in the vernacular so that it would be more readily accessible to English mariners. The book is divided into three major sections. In the first section, Greenwood summarizes the "Doctrine of the Sphere," which provided introductory material on how to find the parallax for the Sun, Moon, and planets. He followed closely **Tycho Brahe**'s method of determining the distance, latitude, and longitude of a comet, planet, or new star using the known positions of two fixed stars as outlined in Brahe's *Progymnasmata*. In this section Greenwood relies heavily on **Christian Severin** (Longomontanus) and on the prognosticator **Vincent Wing**'s *Astronomia Britannica* (London, 1669) in his explanations. In the second section, Greenwood used the astronomical observations of Brahe, Severin, and **Pierre Gassendi** to explain the "Theory of the Planets" and how to calculate planetary positions. When he came to the more difficult problem of how to explain the elliptical path of a planet, Greenwood used **Ismaël Boulliau** as his guide rather than trying to use **Johannes Kepler** or others, because Boulliau "makes the operation more facile." Finally, in the third section of his book, Greenwood appended tables of planetary positions calculated according to the method he outlined in Section 2. Apart from the tables, Greenwood included a short discussion of the dating of the Creation, which he places at 3,949 years before the birth of Christ. He also included a list of observations made by several astronomers of solar and lunar eclipses and a list of the latitude and longitude positions of major cities in Europe.

Derek Jensen

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Gregoras, Nicephoros

Born **possibly Constantinople (Istanbul, Turkey), 1291–1294**
Died **possibly Constantinople (Istanbul, Turkey), 1358–1361**

After studying under **Theodore Metochites**, Nicephoros Gregoras ran a monastery school at Constantinople. A very accomplished scholar in many fields, including theology and hagiography, he is remembered as both a historian and an astronomer. The latter reputation comes from his commentary on **Ptolemy** and his work to reform the Julian calendar in order to fix the date of Easter. Gregoras successfully predicted an eclipse in 1330; it was one of the last acts of Byzantine astronomy.

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Gregory [Gregorie], David

Born **Aberdeen, Scotland, 3 June 1659**
Died **Maidenhead, Berkshire, England, 10 October 1708**

Born into a wealthy family, Newtonian advocate David Gregory was a nephew of **James Gregory**, inventor of the Gregorian telescope. His father (David Gregorie) became heir to the family estate, owing to the murder of his older brother. David Gregorie had 29 children from two wives, of whom David was the third son from the first wife.

Gregory studied at Marischal College, part of the University of Aberdeen, between 1671 (when he was only 12 years old) and 1675, but took no degree. He held an MD and was admitted to the College of Physicians in Edinburgh, practicing medicine. Gregory was awarded MAs by Edinburgh and Oxford universities at the time of his academic appointments.

At the age of 24, Gregory was appointed professor of mathematics at the University of Edinburgh where he taught Newtonian theory, one of the first (or possibly the first) university teacher to do so. Unsettled by political and religious unrest in Scotland – in 1690 he refused to swear an oath of loyalty to the English throne before a visiting parliamentary commission – Gregory became Savilian Professor at Oxford University in 1691, supported by **Isaac Newton**, whom he shamelessly courted. He became a fellow of the Royal Society in 1692, but was not active in the society except in the papers that he submitted for publication.

In 1702, Gregory published *Astronomiae physicae et geometricae elementa*, an account of Newton's theory. He was a member, with Newton, of the committee of referees appointed to supervise the printing of **John Flamsteed**'s observations made at the Royal Observatory at Greenwich, which culminated in the forced publication of Flamsteed's *Historia Coelestis* (1712). Gregory supported Newton's claim against **Gottfried Leibniz** as the inventor of the calculus.

Gregory worked on mathematical series, not always successfully: He published a wrong-footed derivation of the catenary, which Leibnitz gleefully showed to be erroneous. He also published on optics. In *Catoptricae et dioptricae sphericae elementa* (1695), Gregory speculated about the possibility of making achromatic refracting telescopes using two different media. He did so by making an analogy with the human eye. In fact, the eye is far from achromatic, but his idea is on the right lines to make an achromatic lens.

David Gregory was mostly a theoretician. Flamsteed, no friend after the *Historia Coelestis* affair, thought him a closet astronomer. Gregory was taken ill (of consumption or smallpox) on a journey from Bath to London and died at an inn.

Paul Murdin

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Gregory, James

Born **Drumoak near Aberdeen, Scotland, November 1638**
Died **Edinburgh, Scotland, October 1675**

Telescope designer James Gregory was the third son of Reverend John Gregory, Minister of Drumoak in the County of Aberdeen, Scotland, and his wife, Janet Anderson. Gregory attended a grammar school and later graduated from Marischal College. From an early age, Gregory displayed extraordinary mathematical talent.

In 1663, Gregory published a treatise, entitled *Optica Promota*, in which he submitted a novel design for a reflecting telescope. The Gregorian reflector consists of a centrally perforated concave parabolic primary mirror, combined with a smaller concave ellipsoidal secondary mirror. By placing the secondary within the diverging cone of light beyond the focal point of the primary, the secondary mirror reflects a converging beam to the final focal point, located on the opposite side of the primary mirror, where it is magnified by an eyepiece. This relatively compact optical configuration is theoretically sound and provides an erect image suitable for terrestrial use. Unfortunately, the precise figuring of the aspherical conic sections of the mirrors proved to be beyond the capabilities of contemporary opticians. After several abortive attempts were made by London opticians to fabricate a working example, Gregory abandoned the pursuit.

The simpler form of reflecting telescope proposed by **Isaac Newton**, which replaced Gregory's concave ellipsoidal secondary mirror with a planar mirror inclined at 45° to the optical axis, proved far more practical. The first working example of a reflecting telescope of the Newtonian form was demonstrated in 1668 and presented to the Royal Society of London in 1672.

A successful Gregorian reflector was not produced until 1674, when the versatile English polymath **Robert Hooke** constructed an operative telescope on the Gregorian principle. During the 1730s, optician James Short mastered the art of figuring aspherical mirrors. Short figured many fine Gregorian reflectors with apertures as large as 18 in. Yet, the Gregorian design was largely abandoned during the 19th century in favor of the more compact Cassegrain form, in which a convex hyperboloidal secondary mirror is placed before the focus of the telescope's concave parabolic primary mirror.

Gregorian reflectors were revived in the 20th century, however, as the chosen design for NASA's Orbiting Solar Observatories [OSOs]. Because the concentration of sunlight (in a converging beam) could be potentially harmful to the secondary mirror of a Cassegrain system, Gregory's design was adopted for the Solar Maximum Mission and related solar telescopes.

In 1664, Gregory traveled to Italy, where he spent the majority of his time at the University of Padua. There, he derived the binomial series expansion and the underlying principles of the calculus independently of Newton. Gregory also published two mathematical treatises while in Italy. He returned to Great Britain around Easter of 1668, and was elected a fellow of the Royal Society.

Later that year, Gregory was appointed to the Regius Chair of Mathematics at Saint Andrews University, Scotland, where he carried out important mathematical and astronomical work. He independently derived the Taylor series expansions for several trigonometric and logarithmic functions. His observations of the interaction of sunlight with a seabird's feather anticipated the principle and invention of the diffraction grating. In 1669, Gregory married Mary (*née*) Jamieson, the widow of Peter Burnet. The couple had three children.

On one occasion, Gregory returned to Aberdeen and held a collection outside of church doors to raise money for an observatory – the first in Great Britain. He also collaborated with French colleagues to observe a lunar eclipse in a successful attempt to determine the longitude difference between Saint Andrews and Paris.

In 1674, Gregory departed Saint Andrews for Edinburgh University, where he acquired that institution's first chair of mathematics. Within a year of assuming the post, however, he suffered a stroke that left him blind. He died several days later.

His manuscripts are held at the Saint Andrews University Library.

Thomas A. Dobbins

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Gregory of Tours

Flourished **(France), 6th century**

Bishop Gregory described a sequence of stars by which to count the hours of night, so that monastic prayers could be said at the designated times.

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Grienberger, Christopher

Born **Hall, (Switzerland), 1564**
Died **Rome, (Italy), 11 March 1636**

Christopher Grienberger was the first important Jesuit to embrace Copernicanism and to support **Galileo Galilei**. Grienberger entered the Jesuit order in 1590 and after his normal course of studies in rhetoric, philosophy, and theology, he started his studies in astronomy and mathematics. After this he taught mathematics at Graz, Austria. He then went to assist, and later (in 1612) replace, **Christopher Clavius**, S. J., as professor of mathematics at the Roman College, where he began by helping Clavius in gathering one of the earliest collections of data on novae.

A correspondent of Galilei, Grienberger was a strong supporter of the Copernican system and offers a good example of the dilemma of Jesuit scientists. He was convinced of the correctness of Galilei's heliocentric teachings as well as the mistakes in **Aristotle**'s doctrines on motion. But because of the rigid decree of his Jesuit superior general, Claudius Aquaviva, obliging Jesuits to teach only Aristotelian physics, he was unable to openly teach the Copernican theory. He expressed disgust at the Church's treatment of Galilei, but he also stated that if Galilei had heeded the advice of Jesuits and proposed his teachings as hypotheses, he could have written on any subject he wished, including the two motions of the Earth.

Grienberger verified Galilei's discovery of the four satellites of Jupiter as well as the phases of Venus. In March 1611, he organized an ambitious convocation celebrating Galilei: a *festa Galileana*. At this gathering of cardinals, princes, and scholars, the students of Clavius and Grienberger expounded Galilei's discoveries to his immense delight. During the *festa* the Jesuits provided ("to the scandal of the philosophers present") a demonstration with very suasive evidence that Venus travels around the Sun. Galilei was much assured by this expression of support, and for his part had been anxious to have this backing of the Jesuit astronomers who later would respond to a request from the Holy Office confirming Galilei's discoveries.

Galilei's discovery of sunspots created problems with the most intransigent Aristotelians who taught that the Sun was a perfect sphere without blemish. Grienberger confirmed the presence of sunspots, and therefore the corruptibility of the Sun, which contradicted Aristotle, thereby challenging the legislation then in force in the Society of Jesus. Grienberger let it be known that it was only this latter constraint of religious obedience that prevented him from teaching about sunspots and the heliocentric theory. In fact, Grienberger stated that he was not surprised that Aristotle was wrong in these two cases, since he himself had demonstrated that Aristotle was wrong in stating that bodies fall at different velocities.

Grienberger conducted a public disputation concerning the opposing positions held by Galilei and Aristotle on floating bodies during which he adopted the position of Galilei, once again demonstrating that he was in complete agreement with Galilei's theories.

Joseph F. MacDonnell

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Grigg, John

Born **Isle of Thanet, Kent, England, 4 June 1838**
Died **Thames, New Zealand, 20 June 1920**

Educated at least in part in the shadow of the Greenwich Observatory, John Grigg developed an active interest in astronomy before age 15, but that interest was not put to action until much later in his life. He married in 1858, immigrated to New Zealand in 1863, and settled in Thames. There Grigg established himself as a music merchant, selling instruments, giving lessons, tuning pianos, and conducting a local chorus. The 1874 transit of Venus revived his latent interest in astronomy and led to the construction of a modest observatory. Grigg was mainly a recreational observer until after his retirement from business in 1894. Thereafter, however, he became intensely interested in observing comets. His location far to the south, together with the low number of observatories in the Southern Hemisphere, favored his emergence as an important comet observer. Grigg was frequently the last person to observe a comet after perihelion if it retreated in southern skies. Grigg made independent discoveries of three comets that are named in his honor: 26P/1902 O1 (Grigg–Skjellerup), C/1903 H1 (Grigg–Mellish), and C/1907. His notice of 26P/1902 O1 was apparently lost in transit to Baracchi in Melbourne, and there are other known observations from that apparition; comet 26P remained lost until rediscovered in 1922 by **John Skjellerup**.

Thomas R. Williams

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Grīḡōriyōs Bar ʿEḇrāyā

➜ **Barhebraeus: Gregory Abū al-Faraj**

Grīḡōriyōs Bar ʿEḇroyo

➜ **Barhebraeus: Gregory Abū al-Faraj**

Grimaldi, Francesco Maria

Born **Bologna, (Italy), 2 April 1613**
Died **Bologna, (Italy), 28 December 1663**

Francesco Grimaldi was a pioneer in lunar mapping and a leading physicist, the discoverer of diffraction. His parents were Paride Grimaldi and Anna Cattani. He entered the Jesuit order in 1632, studied philosophy in Parma and Ferrara, and studied theology in Bologna. After this he undertook the study of astronomy under another Jesuit, **Giovanni Riccioli**, who would be his coworker for the rest of his life. Grimaldi held the post of professor of mathematics and physics at the Jesuit college in Bologna for many years.

The astronomical work of Grimaldi was closely related to that of Riccioli, who is known especially for his *Almagestum novum*, published in 1651. Riccioli gave a great deal of the credit to Grimaldi for the remarkable success of this publication. He especially praised Grimaldi's ability to devise, build, and operate new observational instruments. In 1640, Grimaldi conducted experiments with Riccioli on free fall, dropping weights from a tower and using a pendulum as timer. Grimaldi's contributions also included such measurements as the heights of lunar mountains and the height of clouds.

Grimaldi is responsible for the practice of naming lunar regions after scientists rather than after ideas such as "tranquility." With Riccioli, he composed a very accurate selenograph. It was much more accurate than any lunar map up to that time. Across the top is written: "Neither do men inhabit the moon nor do souls migrate there."

This selenograph is one of the best known of all lunar maps and has been used by many scholars for lunar nomenclature for three centuries. Astronomers took turns naming and renaming craters, which resulted in conflicting lunar maps. In 1922 the International Astronomical Union [IAU] was formed, and eventually eliminated these conflicts and codified all lunar objects: 35 Jesuit scientists are now listed in the National Air and Space Museum [NASM] catalog, which identifies about 1,600 points on the Moon's surface. This is not surprising, since recent histories emphasize the enormous influence Jesuits had not only on mathematics but also on the other developing sciences such as astronomy.

Grimaldi was one of the great physicists of his time and was an exact and skilled observer, especially in the field of optics. He discovered the diffraction of light and gave it its name (meaning "breaking up"). He also laid the groundwork for the later invention of the diffraction grating. Realizing that this new mode of transmission of light was periodic and fluid in nature, Grimaldi was one of the earliest physicists to suggest that light was wavelike in nature. He formulated a geometrical basis for a wave theory of light in his work *Physico-mathesis de lumine* (1666). This was the only work published by Grimaldi himself. However, 40 of his articles are published in the *Almagestum novum*. It was the *de lumine* treatise that attracted **Isaac Newton** to the study of optics. Later, Newton and **Robert Hooke** (both of whom quoted Grimaldi's works) would use the term "inflexion," but Grimaldi's word has survived.

There is a prominent crater on the Moon's eastern limb named for Grimaldi.

Joseph F. MacDonnell

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Groombridge, Stephen

Born **Goudhurst, Kent, England, 7 January 1755**
Died **Blackheath, (London), England, 18 March 1832**

The English retail merchant and amateur astronomer Stephen Groombridge conducted an extensive observation program to catalog all the stars brighter than magnitude 8.5 between declination +38° and the North Celestial Pole. The Groombridge Catalogue of 4,243 stars prepared from his observations is highly regarded as the earliest accurate observations of these stars.

Groombridge erected a private observatory at Blackheath, within less than a mile of the Royal Greenwich Observatory. He purchased a state-of-the-art reversible transit circle from a leading instrument maker of the period, Edward Troughton. With this superior facility in hand, in 1806 Groombridge commenced the compilation of a catalog of all stars brighter than eighth magnitude within 50° of the North Celestial Pole. Groombridge refined procedures for making such measures as well as his apparatus, and was diligent in making observations. His convenient observatory was adjacent to and easily accessible from his home. It was not uncommon for Groombridge to leave guests at the dinner table for a few minutes while he opportunistically completed measures for a star that was due on the meridian.

Groombridge completed his raw observations in 1816, but reduction of the data was still a burden. He revised and improved reduction procedures by computing tables of standard values, but after suffering a stroke in 1827 was unable to complete the reduction of his observations prior to his death. An intervention by **Richard Sheepshanks** stopped the posthumous publication of a crudely finished catalog of the Groombridge observations. Astronomer Royal **George Airy** then edited a proper reduction of Groombridge's observations using more appropriate procedures. The Groombridge Catalogue was finally published in l838. It remained a standard catalog for nearly half a century. It is a testimony to the inherent quality of Groombridge's observations that, 80 years later, Groombridge's observations were once again subjected to reduction by **Frank Dyson** and W. G. Thackeray of the Greenwich Observatory using even more modern reduction techniques. That second edition of the Groombridge Catalogue was published in 1905. **Arthur Eddington** relied on the 1905 edition of the Groombridge Catalogue for his studies of the motions of galactic stars, claiming that no earlier star catalogs were satisfactory for that purpose. The Groombridge transit circle is preserved at the London Museum of Science.

Thomas R. Williams

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Anon. "Richard Sheepshanks." *Monthly Notices of the Royal Astronomical Society* 16 (1856): 90–97, esp. p. 92.

Grosseteste, Robert

Born **Stowe, Suffolk, England, after *circa* 1168**
Died **Lincoln, England, 9/10 October, 1253**

Some scholars consider the work of Robert Grosseteste to mark the beginnings of modern experimental science.

Although Robert Grosseteste, or "Greathead," was born into the poorest class of feudal society, he received formal education from his earliest years. Evidence for the first five and a half decades of his life is scanty. We know that he worked in the employ of Bishop William de Vere of Hereford until the latter's death in 1198. The cathedral school of Hereford was a renowned center for study in the liberal arts, theology, law, and the natural sciences; some of its masters were acquainted with Arabic learning. The period of Grosseteste's life between 1198 and 1225 is subject to a controversy that has broad implications for understanding his place in history. According to a hypothesis first advanced by Daniel Callus in 1955, upon leaving Hereford, Grosseteste became master of arts at the University of Oxford. When studies were suspended there between 1209 and 1214, he immigrated to Paris. As the University of Oxford reopened, Grosseteste was made head of its schools and subsequently became its first chancellor. In 1986, the late Sir Richard Southern challenged this account, claiming that Grosseteste never studied or taught outside England. Moreover, according to that eminent British historian, Grosseteste's association with Oxford University began only around 1225. He thus spent his most formative years at provincial schools.

While the Callus account considers Grosseteste to be part of the mainstream of Scholastic education, centered as that was on theological concerns as defined at the University of Paris, Southern's revisionist interpretation regards him as a somewhat eccentric thinker whose interests were shaped by the English scientific tradition (with forerunners such as **Adelard of Bath**, Daniel of Morley, and Alfred of Shareshill). For Callus and his followers, then, Grosseteste was a conservative theologian who cultivated some scientific interests on the margin of his career. For Southern, on the other hand, Grosseteste was a scientist turned theologian – a theologian, moreover, whose "English mind" (thus the subtitle of Southern's book) inevitably led him into controversy with the pope.

From 1225 onward, documentary evidence for Grosseteste's life becomes more abundant. In 1225, he was made deacon at Abbotsley, in the diocese of Lincoln. This was the first step in an ecclesiastical career that would, in 1235, raise him to the level of bishop of Lincoln. Between *circa* 1229 and 1235, Grosseteste lectured to the Franciscans at their study-house in Oxford. After his appointment as bishop, pastoral care for the people in his diocese became one of Grosseteste's principal occupations; nonetheless, some of his most important philosophical and theological works date from this period as well. Early in 1253, Bishop Grosseteste learned that Pope Innocent IV had bestowed an important ecclesiastical office in his diocese to one of the pope's own nephews, unqualified for the job. Furious, Grosseteste refused to obey the pope's order, a decision that is again subject to vastly different interpretations. In the eyes of Southern, it makes Grosseteste a kind of proto-reformer, and one who failed tragically; for a Catholic scholar such as James McEvoy, Grosseteste's courageous reaction convinced the pope of the failings of his own *curia*.

Robert Grosseteste was a man of unusually wide-ranging interests. His scientific writings – on astronomy and its practical applications for the calculation of the ecclesiastical calendar, meteorology, comets, the tides, the understanding of natural laws in terms of geometry, and light and optics – were mostly composed before 1235. The method displayed in some of them has won him acclaim as the inventor of experimental science. But once again this claim, made by A. C. Crombie in 1953, is deeply disputed. Grosseteste did not, however, limit himself to science in his early years. Already before 1230, he compiled a highly original index of theological sources that attests to his detailed and broad knowledge of the field, apart from showing acquaintance with works of Greek, Roman, and Arabic provenance. He also wrote extensively on Scripture.

Many of these interests and sources–natural science, Arabic learning, scriptural studies, theology, Aristotelian physics–flow together in Grosseteste's philosophical masterpiece, the short treatise *De luce* (*On light*). *De luce* contains Grosseteste's principal contribution to astronomy: an account of the origin of the universe through the self-diffusion of light. The treatise begins with the assertion that light is the first form of corporeity. Following an Arabico–Jewish tradition of thought, Grosseteste holds that matter itself is dimensionless, being extended in space only in conjunction with this form of corporeity. At the beginning of the universe, then, light rushed out from a single point, carrying matter with it. Light spread itself instantaneously and equally in all directions, until matter became so thin that no further rarefaction was possible. At this point, the process came to a halt, forming the sphere of the first firmament. In a series of original mathematical propositions on relative infinities, Grosseteste shows that only an infinite "plurification" of light could yield the finite dimensions of the universe.

However, light's power of self-diffusion was not exhausted by the formation of the outermost sphere, and the matter below it remained susceptible to greater rarefaction. The process of self-propagation therefore reversed, with light now traveling inward from the first firmament toward the center of the universe. This process came to a standstill when, again, the matter that light carried with itself reached the limits of its possible rarefaction and congealed, as it were, in the second sphere. Since the matter below the second sphere was denser than that below the first, the process of self-diffusion could then start again from the second sphere. Grosseteste himself describes this bellows-like movement as an "assembling which disperses" (*congregatio disgregans*): As light carried matter with itself, it dispersed it, but only to assemble it into bodies of increasing density whenever the process of dispersal reached its natural limits. This alternating movement of expansion and contraction occurred nine times, engendering the nine celestial spheres of the universe, with the earth at its center.

On the one hand, the cosmogony of the *De luce* sketches the outlines of an ambitious scientific project: that of comprehending the origin and structure of the universe by means of the mathematical laws that govern the self-diffusion of light. On the other hand, *De luce* has far-reaching theological implications. Standing in the Augustinian tradition of light metaphysics, Grosseteste took literally the biblical statement according to which "God is light" (1 John 1:5). His cosmogony was an attempt, then, to understand the creative dynamism through which God became, and remains, present in the universe.

Philipp W. Rosemann

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Grotrian, Walter

Born **Aachen, (Nordrhein-Westfalen), Germany, 21 April 1890**
Died **probably Potsdam, (Germany), March 1954**

Potsdam Astrophysical Observatory director Walter Grotrian codiscovered (along with **Bengt Edlén**) the million-degree temperature of the solar corona. His Grotrian diagrams (of atomic levels) enable one to see the relationships between the spectral lines produced by a particular atom or ion.

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Grubb, Howard

Born **Rathmines, Co. Dublin, Ireland, 28 July 1844**
Died **Monkstown, Co. Dublin, Ireland, 16 September 1931**

Howard Grubb and his father Thomas Grubb were noted Anglo-Irish telescope makers who supplied instruments to many British and other observatories during the 19th and early 20th centuries.

Howard Grubb was educated at North's school in Rathmines, Dublin. He entered Trinity College to study engineering in 1863. However, in 1866 his education was cut short by his father, who asked him to join his optical workshop for the construction of the Great Melbourne Telescope. By 1869 they were partners in a specialized optical business and were advertising for astronomical and photographic work.

Thanks partly to influential friends, such as the physicist **George Stokes** and the Armagh astronomer **Thomas Robinson**, Grubb secured a contract to supply a 15-in. refractor/18-in. reflector combination telescope to **William Huggins**, one of the pioneers of astrophysics, a discipline then undergoing rapid development. This led to other contracts for the Royal Observatory, Edinburgh, and for Lord Lindsay's private observatory at Dun Echt, Scotland. In connection with the latter, Grubb became acquainted with the energetic Scottish-born astronomer **David Gill**, who was to become the main force behind technical improvements to the firm's telescope designs and a general booster of Grubb's work.

In 1875, Grubb secured the contract for the construction of what was briefly the world's largest refractor, the 27-in. Great Vienna Telescope. To accommodate this work he constructed a special factory, the "Optical and Mechanical Works, Rathmines," which remained the location of his business until 1918. The telescope was installed in Vienna in 1882.

The 1880s was a period of great activity for Grubb and saw the construction of many small and medium-sized instruments. With the advent of photography as a major astronomical technique in the late 1880s, Grubb started to develop telescope drive systems that permitted precise tracking over long periods. This required refinements to the drive gearing and regulation of the clockwork. He devised a precision gear-cutting technique and also invented a phase-locked loop system for synchronizing the drive to a regulator clock. With the advent of the *Carte du Ciel* and *Astrographic Catalogue* project Grubb received orders for six special telescopes with wide-field lenses. Meeting the specifications of the latter cost him considerable trouble and almost led to a nervous breakdown: The optimization of a large two-component lens for wide fields and blue-sensitive plates is a difficult task that was, at the time, poorly understood theoretically.

The 1890s saw the construction of a 24-in. telescope for the Royal Observatory (Cape of Good Hope) and a 26-in. telescope for the Royal Greenwich Observatory. Both these instruments were photographic refractors, made achromatic for the blue light that alone could be photographed with early plates. A 30-in. reflector (mirror by **Andrew Common**) was mounted on the same stand as the 26-in. reflector. A 28-in. refractor (optics and tube only) was constructed for the Royal Greenwich Observatory. This was Grubb's largest lens.

Besides refracting telescopes, Grubb supplied many other instruments. A large heliostat was made for the Smithsonian Institution in Washington. A number of reflectors were also constructed. The largest of these were 24-in. instruments for the Royal Observatory in Edinburgh, Scotland, and for William Edward Wilson's (1851–1908) observatory in Daramona, Ireland. In about 1896, Grubb refigured the 36-in. mirror of the Crossley reflector for the Lick Observatory.

Up to this time, Grubb himself did much of the precision optical work on his telescopes. He was open about his methods and gave public lectures and demonstrations on the subject. Around 1900 he turned his attention to military optics. The construction of periscopes for submarines, then becoming an important element in naval warfare, came to occupy a large part of his efforts. Nevertheless, telescope construction continued, including a 24-in. photographic refractor for the Radcliffe Observatory in Oxford. Before the outbreak of World War I in 1914, Grubb received contracts for a 26.5-in. refractor for Johannesburg, South Africa, and a 40-in. reflector for Simeis in the Crimea.

World War I put a stop to civilian work, and the factory was turned over wholly to military optical production. The resurgence of Irish nationalism at this time caused the removal of the works from Dublin to St. Albans (near London) for security reasons, this being completed as the war ended. The inflation and labor unrest that followed were more than the aging Grubb could cope with, and the business faltered. Work on the telescopes that had been ordered slowed to a snail's pace. The firm went into liquidation early in 1925. It was purchased by Sir Charles Parsons (1854–1931), the developer of the steam turbine and the youngest son of the telescope-builder **William Parsons**, third Earl of Rosse. Parsons reconstituted the firm as Grubb Parsons and set up a new factory at Newcastle upon Tyne. Only a few key personnel such as Cyril Young, the works manager from 1910, and J. A. Armstrong, the chief optician, were kept on. Howard Grubb was forced to retire and returned to live in Dublin. The reconstituted company survived until 1985.

Grubb married Mary Hester Walker of New Orleans, Louisiana, USA, on 5 September 1871. They had five children. Three of the sons were at various times involved in the business. The oldest, Howard Thomas Grubb, died young, of rheumatic fever. George Rudolph

Grubb left for India in 1900, and Romney Robinson Grubb was with the firm and its successor in Newcastle upon Tyne until 1929. Howard Grubb was elected Fellow of the Royal Society [FRS] in 1883 and was knighted in 1887.

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Grubb, Thomas

Born **Waterford, Ireland, 4 August 1800**
Died **Dublin, Ireland, 19 September 1878**

Thomas Grubb and his youngest son **Howard Grubb** were noted Anglo–Irish telescope makers. Their instruments were the mainstays of many British and other observatories around the world during the 19th and early 20th centuries.

Thomas Grubb's interest in astronomy appears to have been stimulated by his acquaintance with Reverend **Thomas Robinson**, director of Armagh Observatory from 1823 to 1882, who had a finger in every Irish scientific pie. Robinson was to be an indefatigable promoter of both Grubbs.

Thomas Grubb was of Quaker descent. His father, William Grubb, was a farmer, and Thomas was born of his second marriage, to Eleanor Fayle. Thomas Grubb's educational background is unknown. By 1832 he was the proprietor of a foundry in Dublin and had obtained a contract to supply an equatorial mounting for a 13.3-in. Cauchoix lens (at the time, the largest in the world) owned by a wealthy Irish amateur astronomer, **Edward Cooper** of Markree. The uniquely rigid instrument that Grubb constructed, using masonry and cast iron, can be contrasted with the wooden mounting of the Great Dorpat Refractor of Joseph von Fraunhofer, considered to be the state-of-the-art in telescope design at that time.

Shortly thereafter, Grubb constructed a 15-in. speculum-metal reflector for Robinson. This was the first substantial reflector on an equatorial mounting – the earlier instruments constructed by Sir **William Herschel** having been on simple wooden altazimuth frames. Robinson's telescope also incorporated, for the first time, Grubb's mirror support system based on equilibrated levers, essentially the nested triangular support system used in many instruments up to the present day. Parts of this instrument, including the mirror cell, still exist at Armagh. His mirror suspension system was adopted by **William Parsons** (Lord Oxmantown, later third Earl of Rosse) for his giant telescopes. Parsons referred to Grubb as "a clever Dublin artist" in the description of his 36-in. telescope. Other early refractors constructed by Thomas Grubb were the Sheepshanks 6.75-in. refractor for the Royal Greenwich Observatory (*circa* 1839) and the West Point refractor (*circa* 1841). In addition, he built experimental apparatus for various local and British scientists and scientific expeditions. Grubb was elected member of the Royal Irish Academy in 1839.

In 1840, Grubb became "engineer to the Bank of Ireland," to which he supplied specialized and complex printing machinery for banknote production.

The only substantial telescope constructed by Grubb in the following 20 years was the South Refractor – the donor of its lens was Sir **James South** – of Dunsink Observatory, then the property of Trinity College, Dublin. The project appears to have been started before the lens became available. Anticipating that his firm would make the lens, Grubb constructed a complicated polishing machine, described by Robinson in *Nichol's Cyclopaedia* of 1857.

In 1854, Grubb described ray-tracing work he had been doing on microscope objectives, perhaps the first known use of this technique. According to M. von Rohr, Grubb was the first person to have properly understood the field properties of camera lenses. Photography was a strong interest at this time, and Grubb was a frequent contributor to the specialized journals on the subject. He held a patent on an achromatic meniscus lens that is said to have been lucrative for him.

Undoubtedly the most ambitious instrument constructed by Grubb was the Great Melbourne Telescope completed at his workshops in 1868. Although initiated in the early 1850s, the project took many years to come to fruition. Most of the leading astronomers of the time were members of the steering committee, on which Robinson played a highly active role, eventually securing the contract for Grubb.

When the work on the Melbourne Telescope commenced, Grubb found himself almost fully occupied with his Bank of Ireland work, so he called on his 21-year-old son **Howard Grubb** to leave Trinity College, where the latter was a student of engineering, to take charge of the project. Thrown into the deep end, Howard enjoyed the experience of casting the large speculum mirror blanks, which he was able to relate in graphic detail 30 years later to **George FitzGerald** (1896).

The telescope was ready for operation in Melbourne in mid-August 1869. Although generally recognized as a great engineering achievement as the first large professional equatorial, it did not prove to be an astronomical success. Of the many problems with this project, one was the choice of a focal ratio of *f*/41 for the Cassegrain focus, which was too "slow" for adequate illumination of the images. Too little attention had been paid to the operational requirements of a large telescope. The expertise required to keep it in order was lacking in Melbourne. Only in recent times has it, or parts of it, contributed to an important astronomical project – the MACHO gravitational lensing experiment.

Following the apparent success of the Melbourne project, Thomas Grubb left most of the day-to-day running of the firm to Howard. Many more contracts for the construction of large refractors began to come in and very soon a separate factory devoted exclusively to telescopes was constructed – the "Optical and Mechanical Works" in Rathmines, Dublin.

In 1826, Grubb married Sarah Palmer of Kilkenny, Ireland. To this marriage were born five sons and four daughters. Mary Anne married Romney Rambaut, a nephew of Robinson and a member of a family that produced more than one astronomer. His eldest son Henry Thomas Grubb succeeded his father as engineer to the Bank of Ireland, while the youngest, Howard, born in 1844, succeeded his father in the telescope-making business.

In his 70s, Thomas Grubb was crippled by rheumatism and, though he took part in business operations, his energy was clearly waning. He is buried in the Mount Jerome Cemetery in Dublin, where the register quaintly lists the cause of his death as "Decline of Life."

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Gruithuisen, Franz von Paula

Born **Haltenberg Castle near Kaufering am Lech, (Bavaria, Germany), 19 March 1774**

Died **Munich, (Germany), 12 June 1852**

Franz Gruithuisen – the last name is of Dutch origin – is chiefly known for his advocacy of a plurality of inhabited worlds and fanciful hypotheses about the Moon and planets, a circumstance that occasioned **Carl Gauss** to speak of "the mad chatter of Dr. Gruithuisen." His childhood was spent at Haltenberg Castle, where the Elector of Bavaria employed his father as a falconer. Family circumstances did not permit anything other than the limited education that some training in surgery involved, and at the age of 14 the impecunious Gruithuisen departed for medical service in the Austro–Turkish War of 1787–1791.

A year or so later, Gruithuisen found employment as a servant in the court of the Elector Karl-Theodor in Munich, where he obtained a small telescope, which he often turned on the Moon. Gruithuisen soon located all the features that appeared in **Johannes Hevel**'s and **Giovanni Riccioli**'s charts. In 1801 Gruithuisen obtained patronage and enrolled as a medical student at the University of Landshut, receiving his Doctor of General Medicine degree in 1808. He translated Hippocrates into German and wrote several medical monographs.

Meanwhile, the great comet of 1811 (C/1811 F1) awakened his boyhood interest in astronomy just as the Munich optician **Joseph von Fraunhofer** began to produce his superior refracting telescopes. In 1812, Gruithuisen, who was personally acquainted with Fraunhofer, bought two: one of 2.4-in. aperture and the other of 4-in. aperture. Inspired by his hero **Johann Schröter**, and emboldened by the improvements in optical science, he sensed an opportunity to gather fresh evidence on the plurality of inhabited worlds.

Thus began a rather aimless survey of the lunar surface, a series of observations that was to make Gruithuisen's name legendary. "We still have much love for the beautiful Moon," he wrote in his *Selenognostische Fragmente* (1821), "and dry reports of observations better hold our attention if we can only think of the possibility of Selenites." This recalled the ideas of Schroeter and led to the discovery of the "colossal structure, not dissimilar to one of our cities," that came to be known as the "City in the Moon" (a regular but natural arrangement of ramparts that Gruithuisen first observed on the morning of 12 July 1822). Others sought and found this fabled feature, while Gruithuisen himself went on to look for further evidence of an inhabited Moon. A full account of the "city" and other observations are in his *Entdeckung vieler deutlichen Spuren der Mondbewohne* … (1824).

During the 1830s, Gruithuisen extended his advocacy to Mercury and Venus, even to comets. His 1833 interpretation of the Ashen Light of Venus, as the festival illumination put on by the inhabitants of that planet, vivified the public imagination, although, in **Camille Flammarion**'s opinion, the ideas were fantastic.

In the case of the *Entdeckung*, Gruithuisen's ideas probably contributed to his career advancement. For in 1826, 2 years after its publication, he was appointed professor of astronomy at Munich University, where he was relieved of all administrative work and allowed to concentrate on his research, which continued to be a mixture of first-rate observation and wild speculation. Still, in wider scientific circles he became an increasingly marginal figure.

In his day, however, the planets, like the surface of the Moon, were imperfectly known, and announcements of intriguing and mysterious appearances were rife. Caught up in a web of preconception, imagination, and inadequate resolution, Gruithuisen interpreted his observations simply in the context of analogy and what was then known. He, "assuredly thought, and published, an uncommon amount of nonsense," to cite Reverend **Thomas Webb**. Yet he had great energy, and extensive learning. He was a lynx-eyed observer who used small refracting telescopes to very good effect. He discovered fine details on the lunar surface, and was the first to recognize the bright cusp caps of Venus, features that correspond to the bright polar cloud swirls imaged in ultraviolet by the Mariner 10 and Pioneer Venus space probes. In essence, he was a man who foreshadowed aspects of **Percival Lowell**'s Martian hypothesis, and **William Pickering**'s "new selenography." In the 1830s, as he recoiled from stern opposition to his fantasies, Gruithuisen turned to selenological speculation and, from the accretion ideas of the von Bierberstein brothers (1802) and **Karl von Moll** (1810 and 1820), concluded an impact origin for the craters of the Moon.

Gruithuisen's place in the observational history of the Solar System has never been adequately appreciated. This circumstance is largely due to the fact that the authoritative *Astronomische Nachrichten* refused to publish his work. Accordingly he founded his own journals – *Analekten für Erd und Himmelskunde* (1829–1831), *Neue Analekten für Erd und Himmelskunde* (1832–1836), and *Naturwissenschaftlich-astronomischen Jahrbuche* (1838–1847).

Heinrich Olbers may have referred to him as "that peculiar Gruithuisen." History defines him as an observer of skill and exceptional visual acuity who, in spite of his flights of fancy, is deserving of closer study.

Richard Baum

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Guiducci, Mario

Born **1585**
Died **1646**

Galileo Galilei had been cautioned by the church on his astronomical writings. So his student (and later colleague) Mario Guiducci fronted for him in some discourses.

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Guilelmus de Conchis

➔ **William of Conches**

Guillemin, Amédée-Victor

Born **Pierre, Saône-et-Loire, France, 5 July 1826**
Died **Pierre, Saône-et-Loire, France, 2 January 1893**

Amédée-Victor Guillemin's fame is as an author of works on the physical sciences. He trained in scientific and literary studies at Beaune and Paris and taught mathematics from 1850 to 1860. Guillemin penned articles for a number of political and cultural magazines, and by 1860 he had become the editor-in-chief of a local journal, *La Savoie*, published at Chambéry. Politically, he was one of the defenders of the Republic.

Guillemin wrote a number of books on aspects of physics and industry, and these volumes went through many editions and printings. Among them were *Les chemins de fer* (originally published in 1862, seven editions by 1884), *Les phénomènes de la physique* (1868), *Le monde physique* (originally published as *Éléments de cosmographie* in 1867 and expressly designed for use in secondary schools; the new edition appeared in five volumes from 1881 to 1885), *Les applications de la physique aux science, à l'industrie et aux arts* (1874), and a 17-volume compendium of knowledge about the physical world and the heavens, *Petite encyclopédie populaire* (1881–1891). A number of these books appeared in English translation, occasionally revised by a British author.

Guillemin also wrote specifically on astronomy, some of which formed part of his popular compendium: *Causeries astronomiques: Les mondes* (1861, republished in 1863 and 1864), *Le ciel, notions d'astronomie à l'usage des gens du monde et de la jeunesse* (1864, five editions by 1877), *La lune* (1866, seventh edition in 1889), *Les comètes* (1875, revised edition 1887), *Les étoiles, notions d'astronomie sidérale* (1879), *Les nébuleuses, notions d'astronomie sidérale* (1889), *Le soleil* (1869, revised 1873 and 1883), *La terre et le ciel* (1888, republished 1897), and *Esquisses astronomiques: Autres mondes* (1892).

English translations of Guillemin's astronomical books were very popular. In particular, *The Heavens: An Illustrated Handbook of Popular Astronomy*, edited by **Norman Lockyer** and revised by **Richard Proctor**, first appeared in 1866, 2 years after the French original, and went through nine editions by 1883. *The Sun* was published in London 1 year after its Paris edition, in 1870, and appeared in six editions by 1896. *Wonders of the Moon*, revised by **Maria Mitchell**, appeared in 1873 and again in 1886. *The World of Comets* appeared first in 1877 and was highly regarded as a chronicle of cometary apparitions in an era when there were a number of books on the history of comets, by G. F. Chambers and others.

These works were typically lengthy popularizations of past and recent research, emphasizing scientific questions of the day and presenting summaries of current literature. The English translations included many editorial comments, occasionally arguing with the author. What set Guillemin's works apart, however, were their very large numbers of illustrations, mostly woodcuts, with occasional dazzling chromolithographs. Many of the illustrations presented the viewer with a perspective from the astronomical object itself, such as a view of the rings of Saturn (seen from a supposedly cloud-free planetary surface). Earthbound views of astronomical phenomena often included features of local interest. From edition to edition, illustrations were added and removed, especially the chromolithographs. Guillemin's astronomical works were the most lengthy and best-illustrated volumes available to the public in the last two generations of the 19th century.

The astronomical books of Guillemin did not have the authority of Proctor or Lockyer, the dash of **Camille Flammarion**, or the judgment of **Agnes Clerke**, but they held the field between the heyday of the woodcut and the rise of the halftone at the end of the 19th century. The closest that a later generation came to them was the Phillips-and-Steavenson collection, *Splendour of the Heavens*, after

World War I. Guillemin's aim was to stir the imagination, and the richly illustrated books that spilled forth from his prolific pen did just that.

Rudi Paul Lindner

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Guo Shoujing

Born **Xingtai, Shunde (Hebei), China, 1231**
Died **Dadu (Beijing), China, 1316**

Guo Shoujing was an important Chinese imperial astronomer who contributed to calendaric reform and developed instruments to that end. In his youth, he studied under his grandfather Guo Rong, who was versed in Chinese classics, mathematics, and water conservancy, and then under Liu Bingzhong (1216–1274), who was learned in philosophy, geography, astronomy, and astrology. Among Liu Bingzhong's disciples was **Wang Xun**, who later made the *Shoushi* calendar with Guo Shoujing.

In 1262, Guo Shoujing met Kubilai Khan (ruled: 1260–1294) and was initially appointed as a water conservancy engineer. In 1276, Kubilai Khan ordered him to make a new calendar. At that time, the revised *Daming* calendar of Zhao Zhiwei of the previous Jin dynasty (1115–1234) was still in use, but its errors had accumulated and a more accurate calendar for the new Yuan dynasty (1271–1368) was needed. Although the Yuan dynasty already had a national astronomical observatory (*Sitiantai)*, a new department for the compilation of the new calendar was established; Wang Xun took charge of calculation, Guo Shoujìng of observation. In 1278 or 1279, the department developed into the *Taishiyuan* (Imperial Bureau of Astronomy and the Calendar). The Bureau was constructed in Dadu, and Wang Xun was appointed director, with Guo Shoujing as deputy director; their work was supervised by Xu Heng (1208–1281). In 1280, they established the *Shoushi* calendar, officially promulgated after 1281. Shortly thereafter, both Xu Heng and Wang Xun died, leaving Guo Shoujing to continue to compile the exposition of the *Shoushi* calendar. In 1283, the *Shoushi liyi* (Theoretical exposition of the *Shoushi* calendar) was composed by Li Qian (1223–1302). In 1286, Guo Shoujing was appointed director of the Bureau of Astronomy and the Calendar and completed the monographs devoted to the *Shoushi* calendar. In 1294, he was appointed *Zhi taishiyuan shi* (Governor of the Bureau of Astronomy and the Calendar).

Among the instruments Guo Shoujing created for the Bureau was the *jianyi* (simplified armillary). The *jianyi* is a simplified version of an earlier more complicated armillary sphere used to make observations in the equatorial coordinate system. To this instrument was also attached a device to observe the altitude and azimuth of heavenly bodies. It incorporated both equatorial and hour circles and horizontal and vertical circles. The original *jianyi* is not extant, but a reproduction made in the 15th century is preserved at the Purple Mountain Observatory in Nanjing.

Guo Shoujing also created the *gaobiao* (high gnomon) along with the *jingfu* (shadow tally). The gnomon was used in China since Antiquity to observe the Sun's midday shadow and to determine the winter solstice, which is the fundamental point of time in classical Chinese calendars. Guo Shoujing improved it and made it five times higher than previous traditional gnomons, building it 40 *chi* (12.28 m) high. A huge gnomon constructed by Guo Shoujing and others still exists in Gaocheng, Dengfeng city, Henan province, which is called *Guanxingtai* (Astral Observatory).

The main difficulty in observing gnomon shadows is that the Sun is not a point source, and the shadow's penumbra produces ambiguity in determining the shadow's length. Guo Shoujing overcame this difficulty by using *jingfu*, which is a kind of pinhole camera. The image of the Sun is projected through the pinhole, which is adjusted so that the shadow of the horizontal bar in the window at the top of the gnomon tower exactly passes through the center of the image of the Sun. In this way, the position of the shadow of the bar indicates the exact length of the gnomon shadow, with the height of the bar considered to be the height of gnomon.

Guo Shoujing and his colleagues observed the gnomon shadow using the *gaobiao* several times around the winter and summer solstices, and determined the time of solstices by the method devised by **Zu Chongzhi**. This determination led them to use the fairly accurate length for the tropical year of 365.2425 days in the *Shoushi* calendar. Actually, this value had already been used in the Tongtian calendar (1198) of Yang Zhongfu and was confirmed by Guo Shoujing.

Guo Shoujing and his colleagues determined the point of the winter solstice on the celestial sphere, the time when the Moon passes its perigee, the time when the Moon passes its nodes, the right ascensions of lunar mansions, the times of sunrise and sunset at Dadu, and other similar phenomena. They also conducted astronomical observations at 27 different places, and observed the altitude of the North Celestial Pole, the length of gnomon shadows at solstices, the length of daytime and nighttime, and related events.

Another of Guo Shoujing's important determinations is that of the obliquity of ecliptic. His value was quoted by **Pierre de Laplace** in his *L'exposition du système du monde* (1796) in order to show that the obliquity of the ecliptic is diminishing.

Guo Shoujing and his colleagues compiled the *Shoushi* calendar (1280), which is the most comprehensive, inherently Chinese calendar. They incorporated several features that were superior to those of their predecessors. Almost all Chinese classical calendars used a grand epoch when the Sun, Moon, and planets were assumed to be in conjunction. The *Shoushi* calendar abandoned the artificial grand epoch, and used a contemporary epoch with certain initial conditions obtained by observations. Moreover, the *Shoushi* calendar, like the *Futian* calendar (eighth century), used 10,000 for the denominator in its fractions, avoiding the typical and problematic Chinese calendar usage of fractions with different denominators. Although it was not the first calendar to use this denominator, it was certainly one step toward decimal fractions.

The *Shoushi* calendar adopted the method of the *Tongtian* calendar (1198) of Yang Zhongfu in which the length of a tropical year gradually diminishes. Although it is true that the length of the tropical year changes, the values given by the *Tongtian* calendar and the *Shoushi* calendar are too large. The idea that the length diminishes was abandoned in the *Datong* calendar (1368) of the Ming dynasty

(1368–1644), which otherwise almost completely followed the *Shoushi* calendar.

The *Shoushi* calendar also used some new mathematical features, such as third-order interpolation and a mathematical method to transform spherical coordinates. For the latter, the *Shoushi* calendar employed the method devised by Shen Gua (1031–1095), the famous Northern Song Dynasty polymath and scientist.

Although the *Shoushi* calendar was basically made in traditional Chinese style, the possibility of Indian and Islamic influence was recently pointed out by Qu Anjing. All Chinese calendars before the *Shoushi* calendar used numerical methods to calculate the contact times during eclipses, but the *Shoushi* calendar used a geometrical model, which is similar to Indian and Islamic methods that had already been introduced into China. This topic deserves further research.

The *Shoushi* calendar was also introduced into Vietnam and Korea. It was not officially used in Japan, but was well studied in the early Edo period in the 17th century, and played an important role in the development of astronomy in Japan.

Alternate name

Kuo Shou-ching

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Gūrgān

➜ Ulugh Beg: Muḥammad Ṭaraghāy ibn Shāhrukh ibn Tīmūr

Guthnick, Paul

Born **Hitdorf am Rhein (near Leverkusen), (Nordrhein-Westfalen), Germany, 12 January 1879**
Died **Potsdam-Babelsberg, (Germany), 6 September 1947**

German astronomer Paul Guthnick's name is linked with his pioneering work in the application of photoelectric methods to the measurement of the brightness of celestial bodies.

Guthnick was the son of a master plumber, later a wine merchant. After Gymnasium in Cologne, he entered the University of Bonn to study (1897–1901) mathematics, natural sciences, and especially astronomy with **Friedrich Küstner** and Friedrich Deichmüller (1855–1903). Guthnick received his Ph.D. in 1901 for work with Küstner on the variable-star o Ceti (Mira) and, for economic reasons, also took teaching degrees in mathematics, physics, and chemistry. From 1901 to 1903 he was an assistant at the Berlin Observatory with **Arthur Auwers**, and from 1903 to 1906 at the Bothkamp Observatory near Kiel. He returned to Berlin (then under the directorship of **Karl Struve**) in 1906, and moved with the observatory shortly before World War I to the Babelsberg site. He became professor of astronomy at Berlin University in 1916, succeeded Struve as observatory director in 1921, and married in 1923. Guthnick was elected to memberships or associateships in the Prussian Academy of Sciences, the Accademia dei Nuovi Lincei (Italy), the Royal Astronomical Society (London), and the German Academy of Sciences Leopoldina. A lunar crater is named for him.

Guthnick obtained photoelectric light curves for Mars, the Galilean satellites of Jupiter (leading to the suggestion that they are synchronous rotators), and Titan and Rhea (again supporting synchronous revolution around Saturn). He also did a great deal of work in connection with the Astronomische Gesellschaft Commission for Variable Stars. (His theories for several classes of variable stars, *e. g.*, for Cepheids or for Mira-stars, sometimes seemed a little bit unorthodox.) Guthnick's contribution "Physik der Fixsterne" to the encyclopedic handbook *Kultur der Gegenwart* was much appreciated as a very modern view on the new astrophysics.

Guthnick's development of photoelectric methods (beginning about 1912) was very much influenced by the results of the physicists Julius Elster (1854–1920) and Hans Geitel (1855–1923), who had brought photoelectric measuring methods to a high perfection. Guthnick succeeded in building the first photoelectric stellar photometer, attached to the Babelsberg 31-cm refractor, which enabled him to measure stars down to the eighth magnitude. His idea was to combine spectroscopic and photoelectric observations, and he influenced the instrumental development in close collaboration with the Carl Zeiss firm, Jena. Guthnick's organizational abilities helped develop the Babelsberg Observatory to a first-rate astrophysical institution of the time.

Horst Kant

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Gyldén, Johan August Hugo

Born **Helsinki, (Finland), 29 May 1841**
Died **Stockholm, Sweden, 9 November 1896**

Hugo Gyldén, director of the Stockholm Observatory, was a leading theorist of celestial mechanics and planetary perturbations. He was born into the family of professor Nils Abraham Gyldén and baroness Beata Sofia Wrede. Gyldén was admitted to the University of Helsinki and earned his doctoral degree in 1861.

Gyldén's academic teacher, Lorenz Leonard Lindelöf, guided the young scholar into celestial mechanics. Gyldén then went to Gotha in Germany (1861–1862) as a postdoctoral student of **Peter Hansen**, one of the leading researchers in celestial mechanics. There, Gyldén drafted a dissertation on the orbit of the planet Neptune, which had been discovered 15 years earlier.

To continue his studies, Gyldén relocated to the Pulkovo Observatory in Russia on a grant from the University of Helsinki. There, he determined the declinations of fundamental stars with the vertical circle. In this work, Gyldén had to take into account refraction caused by the Earth's atmosphere. In turn, he developed a new model of refraction, and with it drafted improved refraction tables that were widely used afterward. In 1863, Gyldén was appointed a "permanent astronomer" at the Pulkovo Observatory. He married Therese Amalie Henriette von Knebel in 1865; the couple had four children.

At the Pulkovo Observatory, Gyldén did not neglect celestial mechanics. He began to develop the theory of perturbations. In actual practice, the necessary calculations became insurmountably lengthy. Gyldén tried to shorten the calculations by the use of elliptic functions. With the help of these and suitable differential equations, he was able to make the series converge faster than before, so that there were not so many terms to be calculated. Gyldén implemented these methods in the 1870s and applied them to the orbits of periodic comets.

In 1871, the Royal Swedish Academy of Science offered Gyldén the directorship of the Stockholm Observatory. There, he actively developed the observatory and its instruments while continuing his research on celestial mechanics. Gyldén's aim was to find mathematical forms describing the orbits of the planets, and with the help of these forms to account for their motions during arbitrarily long periods of time. In this way, it would be possible to answer the question of whether the Solar System has a permanent structure.

At first, Gyldén replaced the elliptical orbits of the planets with curves of higher order. In these intermediate orbits, as he called them, disturbances caused by other planets were taken into account. Soon, however, Gyldén noticed that an intermediate orbit was not accurate enough. He then tried to find as general a form as possible for the orbits of the planets, which he called absolute orbits. While an ordinary elliptical orbit was determined by six constants, the "orbit constants" of an absolute orbit must be expressed by time-dependent periodical functions. Gyldén hoped to show that no deviation of a planet's orbit, beyond a certain small value, could ever occur.

Gyldén intended to publish his research on orbital theory as a three-volume work; the first volume was printed in 1893. But he fell ill and died before the second volume could be completed; it was published posthumously in 1908. Afterward, it was demonstrated that Gyldén's notions concerning the existence of absolute orbits are not binding. Nonetheless, his accomplishments in the field of celestial mechanics are undeniable, and influenced other investigators, such as **Marie Andoyer**.

Gyldén was a delegate to the Astrographic Congress in Paris (1877), at which the *Carte du Ciel* project was launched. Many scientific societies and academies appointed him an honorary or corresponding member. Gyldén was also a member of the board, and finally the chairman, of the international organization of astronomers, the German Astronomische Gesellschaft.

Tapio Markkanen

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H

Haas, Walter Henry

Born **New Waterford, Ohio, USA, 3 July 1917**

Walter Henry Haas founded the Association of Lunar and Planetary Observers, and, over his lifetime, provided substantial leadership to the amateur astronomical community in those fields. Interested in astronomy at an early age, Haas observed Nova Herculis 1934, and began a long career of lunar observation in that same year. Between high school and college, he spent a month at the Woodlawn Observatory of **William Pickering** in Mandeville, Jamaica, learning lunar and planetary observing techniques. Haas earned a BS in mathematics at Mount Union College, Alliance, Ohio, and an MA in mathematics at Ohio State University. During his high school and college years, Haas formed a network of relationships with other amateur astronomers with similar observing interests. He published the results of his own work, as well as that of others, in a series of articles in *Amateur Astronomy, Popular Astronomy, Texas Observer's Bulletin,* and *Journal of the Royal Astronomical Soceity of Canada*. From 1941 to 1945, during World War II, Hass assisted **Charles Olivier** with the training of naval and aviation navigators at the University of Pennsylvania. He continued his lunar and planetary observing program with the fine 18-in. Brashear refractor of the Flower Observatory. Many of Haas's wartime observations were submitted to the lunar and various planetary sections of the British Astronomical Association and constituted a main source for their continued activity.

After the war, Haas moved to New Mexico where he was employed as a mathematics instructor and applied mathematician. In 1947, Haas founded the Association of Lunar and Planetary Observers [ALPO] and started publishing its journal *The Strolling Astronomer*, later renamed *Journal of the ALPO*. The initial membership of ALPO was drawn from Haas's network of corresponding observers, including noted early planetary photographer **Latimer Wilson**, Edwin P. Martz (who would later design the camera systems for NASA's Lunar Ranger program), Frank Vaughn Jr., and Hugh M. Johnson (later a pioneer X-ray astronomer). ALPO membership grew rapidly and has since become a stable part of the organization of amateur astronomy in the United States with an international membership. Haas retired as ALPO's director in 1985, but remained active in the association for another two decades.

Thomas R. Williams

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Ḥabash al-Ḥāsib: Abū Jaʿfar Aḥmad ibn ʿAbd Allāh al-Marwazī

Died **probably Samarra, (Iraq), after 869**

Ḥabash al-Ḥāsib (literally, "Ḥabash the calculator," with the intended meaning of "mathematical astronomer") was one of the most original and most influential Muslim astronomers of the formative period of Islamic astronomy. The dates of his birth and death are not known, but according to the bibliographer Ibn al-Nadīm he died as a centenarian. Ḥabash was closely associated with the ʿAbbāsid court; he was active in Baghdad during the reign of Caliph **Maʾmūn** (813–833). Later, he lived and worked in Samarra, which in 838, became the new administrative capital of the ʿAbbāsid Empire.

Ḥabash's biography is yet to be definitively established. The bibliographer Ibn al-Nadīm (died: 995) mentions Ḥabash as a scientist active at the time of Maʾmūn, and Ibn al-Qifṭī (died: 1248) adds that he also lived under the reign of al-Muʿtaṣim. In his own account of the achievements of the *aṣḥāb al-mumtaḥan* – the group of scholars involved in the observational project sponsored by Caliph Maʾmūn whose objective was to check the parameters of **Ptolemy**'s *Almagest* – Ḥabash does not present himself as one of their protagonists, although he was certainly in close contact with them. The earliest certain date associated with him is given by **Ibn Yūnus**, who reports an observation conducted by Ḥabash in Baghdad in the year 829/830 (*i. e.,* 4 years before the death of Maʾmūn). This is also the date associated with many other *mumtaḥan* observations and with the *mumtaḥan* star-table.

Ibn al-Qifṭī attributes a *zīj* (astronomical handbook) to Ḥabash. This was compiled when he was a young man in the tradition of the Indian *Sindhind*, and was based upon the *zīj* of **Khwārizmī**. Also ascribed to him is another smaller work, the *Zīj al-Shāh*, probably following the same Pahlavi tradition as the eponym work by **Fazārī**. The composition of those two non-Ptolemaic *zīj*es must have occurred before 829/830, the year when the *mumtaḥan* observational program was inaugurated. But Ḥabash is best known to his contemporaries and successors for his authorship of a third *zīj*, whose content is almost entirely Ptolemaic, and which became known as "the" *zīj* of Ḥabash.

In the introduction to this latter *zīj*, Ḥabash informs his readers that after Ma'mūn's death he took upon himself the task of revising the observational data gathered by the "*mumtaḥan* astronomers." Hence, inspired by Ptolemy's methodology, he conducted his own observations of the Sun and Moon, and also made repeated observations of the remaining planets at specific times. The latest dates associated with Ḥabash are recorded in his *zīj* – 22 April 849, 17 November 860, and 15 September 868. These dates coincide with the reigns of Caliph al-Mutawakkil (reigned: 847–861) and of his third short-lived successor al-Muʿtazz (reigned: 866–869). We can assume that the *zīj* was finalized after the year 869 and represented Ḥabash's ultimate achievement. A further indication of this is the fact that Ḥabash uses an obliquity of the ecliptic of 23° 35′, a value observed by the **Banū Mūsā** in Samarra in the year 868/869. He could not have been more than *circa* 75 years old at that time, which would then imply that he was not born before *circa* 796. The period 796–894, in fact, seems to be the most reasonable estimate for his life span, and this would make him belong to the same generation as **Abū Maʿshar** and **Kindī**. The usual modern references to him as flourishing *circa* 830 would seem to correspond in actuality to the earliest period of his life.

To summarize, we can divide Ḥabash's scientific career into the following four distinct periods:

1. The early, formative period in Baghdad (*circa* 815–829), during which he became acquainted with the Indian and Persian astronomical systems through the works of Fazārī and Khwārizmī, and composed two *zīj*es based upon these systems.
2. The *mumtaḥan* period (829–834), during which he presumably had close contacts with the *mumtaḥan* group of astronomers in Baghdad and Damascus, and benefited from their new observations and insights. During this crucial period, the superiority of Ptolemy's system became gradually obvious to most specialists. With the resulting consensus in favor of Ptolemaic astronomy and the consequent abandonment of Persian and Indian theories, Islamic astronomy reached a new, stable phase of its development.
3. The post-*mumtaḥan* period, beginning after the death of Ma'mūn in August 833, and possibly based in Damascus, during which Ḥabash pursued his own observational program following the *mumtaḥan* tradition.
4. The Samarra period, covering the last half of his career, during which he finalized his Ptolemaic *zīj* and composed most of his astronomical works that are now extant.

The Ptolemaic *zīj* of Ḥabash, the only one that is extant, is known under four different names – *al-Zīj al-Mumtaḥan* and *al-Zīj al-Ma'mūnī* (because it is based on the observational program of the *mumtaḥan* group under the sponsorship of Ma'mūn), *al-Zīj al-Dimashqī* (presumably because it was also based on observations conducted by Ḥabash in Damascus), and *al-Zīj al-ʿArabī* (because it is based on the Arabic Hijra calendar). There is absolutely no evidence to support the contention that the above appellations might refer to more than a single work. Every reference to "the *zīj* of Ḥabash" encountered in later sources (notably **Bīrūnī** and Ibn Yūnus) is in accord with the single version of the *zīj* by this author that is preserved for us. There is an instance where Bīrūnī mentions the *zīj* of Ḥabash in general terms, and later characterizes the same work with the epithet *al-mumtaḥan*. This *zīj* is the earliest independently compiled Ptolemaic astronomical handbook in the Arabic language that is preserved in its entirety. Undoubtedly, it was also one of the most influential *zīj*es of its generation. Indeed, Bīrūnī, in the early (Khwārizmian) period of his life, utilized it for his own astronomical practice. Although Ḥabash follows Ptolemy's models and procedures very closely, he does introduce several new, improved parameters as well as an impressive amount of original computational methods, some of them undoubtedly of Indian origin or inspiration. His *zīj* also contains a set of auxiliary trigonometric tables, called *jadwal al-taqwīm*, which are of singular importance in the history of trigonometry.

Two copies of this *zīj* are available, one preserved in Istanbul, which preserves fairly well the original text, and a second one in Berlin. The latter is a recension of the original, mixed with materials due to various later astronomers. (A table of concordance with the Istanbul MS is appended to M. Debarnot's survey of the Istanbul MS.) Unfortunately, Ḥabash's *zīj* is yet to be published.

Another work of Ḥabash, his *Book of Bodies and Distances*, is in fact devoted to five different topics of scientific activity conducted under the patronage of Ma'mūn, including an interesting report on the geodetic expedition to determine the radius of the Earth (or equivalently the length of 1° of the meridian). Ḥabash also devoted several works to the topic of astronomical instrumentation. An important treatise on the construction of the melon astrolabe, which he probably invented and whose principle is based on an "azimuthal equidistant" mapping, has been published by E. Kennedy *et al.* (1999). An anonymous treatise on the construction of a highly original but still unexplained universal instrument for timekeeping with the stars, preserved in a unique and incomplete copy, has been published lately, and Ḥabash's authorship has been established. D. King recently suggested that this instrument could be a companion to the medieval European universal dial known as *navicula de venetiis*, which he hypothesizes to be, ultimately, of Islamic origin. Ḥabash also composed treatises on the use of the celestial globe, the spherical astrolabe, and the armillary sphere.

Ḥabash's graphical procedure (a so–called analemma construction) for determining the direction of Mecca (*qibla*) is preserved in a letter of Bīrūnī to an Abū Saʿīd (most probably **Sijzī**), in which the contents of Ḥabash's treatise – not extant in its original form but incorporated in his *zīj* – are summarized. Among several works of his that have not survived are treatises on the construction of the standard planispheric astrolabe, on the prediction of lunar crescent visibility, on the construction of sundials, and on some geometrical problem; also lost are his two critical reports on the observations conducted by the *mumtaḥan* group in Baghdad and Damascus.

François Charette

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Hadley, John

Born **Enfield Chase, Hertfordshire, England, 16 April 1682**
Died **East Barnet, Hertfordshire, England, 14 February 1744**

John Hadley made two major contributions to astronomy – the improvement in the reflecting telescope and the invention of the double-reflecting quadrant. His brother George was the first (1735) to explain the direction of the trade winds as caused by the rotation of the Earth, superposed on an atmospheric circulation (called a Hadley cell) with an updraft near the Equator and downdrafts near latitudes 30° N and S.

Isaac Newton had used a spherical mirror in the telescope that he showed to the public, but he knew that a parabolic mirror would be much better. About 1720, John Hadley, with assistance from his brothers George and Henry, made a speculum mirror with a 15-cm diameter, a focal length of about 157 cm, and a paraboloidal figure. The telescope was shown to the Royal Society in 1721. **Edmond Halley**, who had just become Astronomer Royal, and **James Bradley**, then Savilian Professor of Astronomy at Oxford, tested Hadley's telescope with great success. This major improvement led to the general introduction of reflecting telescopes. In later years Hadley made many Newtonian and Gregorian reflecting telescopes.

Hadley's second success was the invention in 1731 of the double-reflecting quadrant. Thomas Godfrey in Philadelphia made a near-simultaneous invention of the quadrant. It was later called the octant because its arc was ⅛ of the circumference of a circle. This instrument, which he made of wood, proved to be excellent for making angular measurements between pairs of astronomical objects observed from a moving ship. In 1734, Hadley added a spirit level to his octant so that a meridian altitude could be taken at sea when the horizon was not visible. His octant was patented in 1734. About 1757, John Campbell modified the octant into the sextant with an arc of 60°.

Roy H. Garstang

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Hagen, Johann Georg

Born **Bregenz, (Austria), 6 March 1847**
Died **Vatican City, Vatican, 6 September 1930**

Johann Hagen entered the Jesuit order in 1863. He came to America and was the director of the Georgetown University Observatory from 1888 to 1906, before going to the Vatican Observatory, where he remained until his death. Most of his research dealt with variable stars, though he touched on other topics like nebulae in the Milky Way. Hagen also produced a revision of **John Dreyer**'s *New General Catalogue of Nebulae and Clusters of Stars*.

Katherine Bracher

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Hagihara, Yusuke

Born **Osaka, Japan, 28 March 1897**
Died **Tokyo, Japan, 29 January 1979**

Yusuke Hagihara contributed to celestial mechanics and to the development of astronomy in Japan during the reconstruction after World War II. His early years were difficult; his parents divorced, and Yusuke's mother left him soon after he was born. As the financial situation of his father's factory was very bad, Hagihara had financial difficulty in his school days, but he finished his instruction in astronomy at Tokyo Imperial University in 1923 with help from Shinobu Origuch, who was his teacher of Japanese literature at the middle school in Osaka. Hagihara was survived by his wife, Yukiko, who passed away a few years after him; one daughter, Mrs. Ayako Tsuji; and two sons, Michio Fukai, a banker, and Toshio Hagihara, now the president of the Nippon Television Network Company.

In 1925, Hagihara was appointed assistant professor of astronomy at Tokyo Imperial University and was sent to Europe by the Japanese government to study newly developing fields of astronomy. He stayed at Cambridge University for 2 years, where his advisor was mathematician H. F. Baker. Hagihara attended several courses at Cambridge, particularly the lectures on relativity by **Arthur Eddington** and **Paul Dirac**, who often visited Baker to discuss his delta functions. After he came back to Japan in 1925, Hagihara started to give lectures at Tokyo Imperial University. In 1928/1929, Hagihara visited the Department of Mathematics at Harvard University as a Rockefeller fellow. He worked on dynamical systems under **George Birkhoff**, who was writing *Dynamical Systems with Two Degrees of Freedom*. During his stay there Hagihara often visited Harvard College Observatory. His dissertation for a doctor's degree in 1930 was on the stability of satellite systems, particularly Jupiter's Galilean satellites.

In 1931, Hagihara published "Theory of the Relativistic Trajectories in a Schwarzschild Gravitational Field" in the *Japanese Journal of Astronomy and Geophysics*. In it, he derived a rigorous solution for motion of a test particle in a gravitational field by using elliptic functions. In 1935, Hagihara was promoted to full professor. In the 1930s and 1940s, he also published several papers on celestial mechanics, including a series of papers on secular commensurability of minor-planet motions; and on astrophysics, particularly on planetary nebulae.

When his office and house in Tokyo were burned by US air attacks at the end of World War II, most of Hagihara's research materials were destroyed. In autumn 1946, Hagihara was appointed director of Tokyo Astronomical Observatory, one of the research institutes of the University of Tokyo (formerly Tokyo Imperial University). Under very difficult circumstances, he made every effort to reconstruct the observatory, which suffered damage during the war, and to modernize Japanese astronomy. Through his efforts, a 10-m dish for detecting solar radio bursts was constructed at Mitaka, and a 74-in. (188-cm) optical telescope (the first Japanese telescope for astrophysical observations) was installed at Okayama Astrophysical Station. Hagihara had to retire from his professorship at the University of Tokyo in 1957, though he taught astronomy at Tohoku University (Sendai) for 3 years thereafter. Hagihara produced an enormous amount of manuscripts from his lectures at the University of Tokyo, where he had given a 3- to 4-hour lecture every week (until he retired) on celestial mechanics and selected topics, including the topological theory of the three-body problem, equilibrium figures of rotating fluids, and the physics of planetary nebula.

Hagihara was the leader in ionosphere research done by scientists in various fields from Japan in the 1940s and 1950s. He attended the General Assembly of the International Union of Radio Science at Zürich in 1950 as the chief delegate from Japan. For the General Assembly of the International Astronomical Union [IAU], Hagihara was the chief delegate at Stockholm, in 1938, and at Rome, in 1952. Although the invitation was personally extended to him for the General Assembly at Zürich in 1948, he could not attend it because no permission was given to him to go abroad.

After he left Tohoku University in 1960, Hagihara often stayed at the Smithsonian Astrophysical Observatory in Cambridge, Massachusetts, USA, on the invitation of **Fred Whipple**, and gave lectures at the Summer Institute of Dynamical Astronomy organized by Yale University Observatory. During his stay in the United States, he was awarded the James Watson Gold Medal by the National Academy of Sciences, for his outstanding work on celestial mechanics. Also in 1960, Hagihara was appointed president of Utsunomiya University, one of the national Japanese universities, and served a 6-year term.

In 1942, Hagihara began to write the first books on fundamental celestial mechanics in Japanese. However, since it was difficult for any publisher to find paper then, his work was not published. The initial book was published in two parts in Japanese in 1947 and 1949, and in five volumes in English. After the first 700-page volume, subtitled *Dynamical Principles and Transformation Theory*, came the second, *Perturbation Theory* (in two parts of 1,000 pages), published by MIT Press in 1970 and 1972. MIT Press became worried about the size of the manuscripts for the coming volumes, and gave up publishing them. The other three volumes, each in two separate parts, were published by the Japanese Society for Promotion of Sciences. The fifth volume, *Topology of Problems of Three Bodies* (1,500 pages), was published in 1976, when Hagihara was almost 80 years old.

Hagihara was elected a member of the Japanese Imperial Academy in 1949, and was honored by the government with an Order for Cultural Merits. In 1961, at the General Assembly, Hagihara was elected vice-president of the IAU and president of Commission 7 (Celestial Mechanics). He served for 6 years.

Yoshihide Kozai

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Hahn, Graf Friedrich von

Born **Neuhaus, (Schleswig-Holstein, Germany), 27 July 1742**
Died **Remplin, (Mecklenburg-Vorpommern, Germany), 9 October 1805**

Friedrich von Hahn, a correspondent of **William Herschel**, had a well-equipped observatory, publishing on descriptive astronomy; and suggested the Doppler effect 50 years before **Christian Doppler**. Von Hahn came from an old Mecklenburg family. He grew up in Neuhaus, and later studied at the University of Kiel, primarily reading mathematics and astronomy. Hahn was a highly cultured person, devoted to the search for enlightenment. He promoted agriculture in Mecklenburg and provided good medical treatment, advice and support for the elderly and sick on his extensive estates, as well as a high level of education and social welfare.

In 1791, at Remplin, Hahn converted a summerhouse into an observatory with an instrument room and observational platform, and in 1801, added a four-story tower with a rotating dome. Hahn had a set of extremely high-quality instruments at his disposal. Beneath the dome, the principal instrument was a vertical circle by Cary (with a 25-in.-diameter circle, and telescope with a focal length of 33 in. and 2-in. aperture). In addition, there were a 1-ft. universal equatorial and a 4-ft. transit telescope, both by Dollond.

Alongside the observatory building Hahn installed three reflectors – those with a focal length of 20 ft. and apertures of 18 and 12 in., as well as a 7-ft. telescope with an 8-in. aperture, the mirrors for which had been polished by William Herschel. (The mountings were made in Remplin.) After the count's death, the instruments were moved to Königsberg, where they became the initial equipment for the observatory. **Friedrich Bessel** carried out some of his work with this equipment for many years and was full of praise for them.

Hahn's studies produced 20 publications, most of which appeared in the *Berliner Astronomische Jahrbuch*. His main emphasis was on descriptive astronomy – the surfaces of the planets and the Moon, the physical nature of the Sun, the "nebulous stars" (particularly the Andromeda Nebula), the nature of variable stars, optical phenomena, and research into the "matter of light." With regard to the Sun, he endorsed William Herschel's "photosphere theory," which held that the Sun is a cool body similar to a planet. Also like Herschel, Hahn was convinced that stars evolve, but that this takes place so slowly that it cannot be detected directly. In addition, his work *Gedanken ueber die Lichtabwechselung veraenderlicher Sterne* (Thoughts on the variations in light of variable stars, 1795) is significant. In it, he gives a theoretically based explanation of the optical Doppler effect. He wrote: "Now if a star approaches the Earth with a certain velocity, then the light has a shorter path to travel, its particles follow one another more rapidly, and cause the object to appear brighter to the eye. " Thus, Hahn, some 50 years before Doppler, was the first intellectual to draw attention to the relationship between the motion of a light source and the changes thus created in the interval between two luminous events.

After Hahn's death, the observatory fell into disrepair; the main building was soon demolished, and the tower was severely damaged in World War II. In 1983, it was restored as a monument to the history of science.

Jürgen Hamel
Translated by: *Storm Dunlop*

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Hájek z Hájku, Tadeá

Born **Prague, (Czech Republic), *circa* 1525**
Died **Prague, (Czech Republic), 1 September 1600**

Thaddaeus Hagecius was a skilled astronomical observer, who has been called the leading astronomer in Eastern Europe during the late 16th century.

Hagecius (Hájek or Hayck) was born in a wealthy family – his father, Simon, was an expert on literature and a graduate of the University at Prague; his mother, Katerina, who hailed from nobility, died when Thaddaeus was an infant. Hayck studied at numerous European universities (as was common at that time), including a study of mathematics and medicine at the University of Vienna, eventually attaining his bachelor's (1550), master's (1552), and doctor's degrees at Prague University. Though Hayck was briefly a professor at Prague, he gave that up to practice medicine. Hayck published books ranging from biology to human character to brewing beer; he studied cartography and geodesy, and he became the private imperial physician to Emperor Maximilian II and Emperor Rudolph II in Prague. Like his father, Hayck accumulated a large library of books, and he also collected astronomical instruments. Hayck openly attacked other scholars whose ideas or remarks were seen by him as incorrect, and this helped to form the first real critical refereeing system in astronomy.

Hayck was an accomplished observer who was active in the first big circle of European astronomers at that time, whose discussions and publications led directly to the formation of national societies of astronomers in the following centuries. Hayck actively corresponded with other observers, including especially **Tycho Brahe**, on the supernova of 1572 (B Cas) and the comets of 1577 and 1580 (C/1580 T1). Hayck put much effort into his astrometric observations and attained an accuracy that placed him in the top four or five astronomers in Europe. He also discussed astrology with other scholars, and Hayck's many correspondents included Philip Melanchthon.

Hayck also published calendars and a Czech tract on the comet of 1556 (C/1556 D1). He later was tapped by Emperor Rudolph II to look into calendar reform, a topic that Hayck supported. Hayck also recommended that Emperor make Brahe the Imperial Mathematician in 1600 when Brahe was forced out of Denmark, a move that would prove very important in the history of astronomy for bringing together Brahe and **Johannes Kepler** at Prague. Hayck was one of Brahe's chief correspondents, and the two men shared an interest not only in astronomy but also in alchemy.

Hayck preserved a manuscript copy of **Nicholas Copernicus**'s "Commentariolus," a predecessor to the latter's famous *De Revolutionibus* (1543), and gave it as a gift to Brahe. Not only was Hayck a follower of Copernicus's heliocentrism, but his accurate observations of celestial objects were among the best in Europe, and Hayck was open to revising his procedures when criticized by Brahe. For example, Hayck wrote in his tract on the 1577 comet that his observations showed it to be closer than the Moon, but discussion with Brahe led him to retract this view by the time he wrote his tract on the 1580 comet.

Hayck published many works, mostly on nonastronomical topics. But his astronomical publications are quite noteworthy, dealing chiefly with his observations of comets and the Cassiopeia supernova of 1572. Unfortunately, there has been relatively little attention given to Hagecius's observations until recently.

Daniel W. E. Green

Alternate names

Thaddaeus, Hagecius
ab Hayck, Tadeá
Nemicus, Tadeá
Agecio, Tadeá

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Hagecius (1574). *Dialexis de novae et prius incognitae stellae invsitatae magnitvdinis & splendidissimi luminis apparitione, & de eiusdem stellae vero loco constituendo*. Frankfurt. (An impressive work on the supernova of 1572, with a lengthy assessment of his observations followed by shorter tracts on the new star by Cornelius Gemma and Paul Fabricius, short older tracts on comets by Regiomontanus and Vogelin, and letters between Hagecius and other astronomers.)

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Thoren, Victor E. (1990). *The Lord of Uraniborg: A Biography of Tycho Brahe*. Cambridge: Cambridge University Press, pp. 98–99, 522. (Hagecius, or Hayek [as Thoren gives his name], is mentioned extensively in his important correspondence with Tycho over a span of decades, which gives much insight into their relationship.)

Ḥajjāj ibn Yūsuf ibn Maṭar

Flourished **Baghdad, (Iraq), 786–830**

We know next to nothing about Ḥajjāj's personal life, his family, his friends, or his training; we do know that he was one of the most influential translators of the late 8th and early 9th centuries in Baghdad, then the capital of the ʿAbbāsid Empire.

Ḥajjāj translated **Ptolemy**'s *Megále Sýntaxis* (later known as the *Almagest*) and Euclid's *Elements*. In the early 9th century, he translated the *Elements*, apparently on the basis of a single Greek manuscript, into Arabic for Yaḥyā ibn Khālid (died: 805), the Vizier of Caliph **Hārūn al-Rashīd**. In the 820s, Ḥajjāj revised his translation and produced for the then ruling ʿAbbāsid Caliph **Ma'mūn** (reigned: 813–833) a new version described as more sophisticated than his original translation. When and for whom he translated the *Almagest* is unknown. Two manuscripts of Ḥajjāj's translation of Ptolemy's major work are today extant, one of them complete, the second containing only Books I–IV.

Ḥajjāj's translations exercised a long-lasting influence upon the community of Arabic, Persian, Hebrew, and Latin students of Ptolemy's and Euclid's books. It can be detected in the manuscripts representing the second major tradition in the Arabic transmission of the *Almagest* and the *Elements* (and in that of its later offspring in Latin and Hebrew). This second tradition was started by **Isḥāq ibn Ḥunayn**'s translations of the *Almagest* and the *Elements* into Arabic and continued with **Thābit ibn Qurra**'s edition of the two translations. Several of the ten manuscripts of the Arabic *Almagest* extant today and representing this tradition contain some portions of the Ḥajjāj translation, in particular the star catalog. Manuscripts of both traditions, including manuscripts having parts of each, were studied in Andalusia (Spain), in northern Africa, the central lands of the Middle East, Central Asia, and India. Important scholars such as **Abū ʿAlī ibn Sīnā** (in Central Asia and Iran;), **Jābir ibn Aflaḥ** (in al-Andalus), and **Naṣīr al-Dīn al-Ṭūsī** (in Iran) knew and worked with manuscripts of both traditions and commented, sometimes critically, upon them. In the 12th century, **Gerard of Cremona** translated the *Almagest* in Toledo from Arabic into Latin using manuscripts representing the two Arabic traditions. Books I–IX of his translation are based on the work of Ḥajjāj except for the star catalog in the books VII.5–VIII.1, which represents a text mixing the two Arabic traditions. The remaining three books of Gerard's translation are derived from the work of Isḥāq ibn Ḥunayn and Thābit ibn Qurra (Ptolemäus, Vol. 2, p. 3, 1990).

Sonja Brentjes

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Halbach, Edward Anthony

Born **Canby, Minnesota, USA, 5 April 1909**

Edward Halbach gained national prominence in several different astronomical observing programs.

A childhood in rural poverty limited the opportunities for Edward Halbach to learn much about astronomy. After earning a BS in Electrical Engineering (1931) and an MS in Physics (1933) from Marquette University, in Milwaukee, Wisconsin, Halbach was persuaded to help found the Milwaukee Astronomical Society [MAS]. He served as observatory director for the MAS for over 40 years.

As a variable star observer, Halbach encouraged other MAS members to join the American Association of Variable Star Observers [AAVSO] and participate actively as members. MAS members formed an important contingent under the leadership of AAVSO for a number of decades thereafter. He also encouraged meteor observing for the American Meteor Society, designing, building, and operating camera systems that helped determine the height of meteors at a time when such heights were still uncertain. A similar effort was mounted to observe aurorae with simultaneous photography from several locations. MAS aurora observations were assimilated in a program directed by professor Carl Witz Gartlein of Cornell University. Halbach also acted as chairman of the AAVSO Aurora Committee for several years.

During and after World War II, Halbach led a number of solar eclipse expeditions to Canada, Burma, and Somalia in cooperation with professional astronomer **Bertil Lindblad**, and under the sponsorship of the National Geographic Society and United States Army Map Service. He received the National Geographic Society's Franklin L. Burr Award for these services. Halbach also led an early effort for time grazing lunar occultations when that specialized field first emerged under the leadership of David Dunham. Halbach served as the first president of the fledgling Astronomical League, and was a substantial contributor to that organization's leadership in the years that followed its founding in 1947.

Thomas R. Williams

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Hale, George Ellery

Born **Chicago, Illinois, USA, 29 October 1868**
Died **Pasadena, California, USA, 21 February 1938**

American solar astronomer and science administrator George Hale discovered the magnetic field of the Sun, the first body after the Earth found to have one. However, Hale made his greatest impact through his role in founding the observatories at Yerkes, Mount Wilson, and Palomar Mountain in the establishment of the International Union for Co-operation in Solar Research (before World War I), the International Research Council, the International Astronomical Union (after World War I), the administration of the National Research Council during that war, and the transformation of Throop Polytechnic Institute into the California Institute of Technology, in collaboration with **Robert Millikan** and Arthur Noyes. The 1895 founding of the *Astrophysical Journal* by Hale and **James Keeler** began the transformation of American astronomy from a focus on how astronomical bodies move to its modern emphasis on the physical conditions within them, their composition, and their formation and evolution.

Hale was the son of William Hale, head of a successful firm, Hale Elevators, who had hoped his son would follow him into the business, but who was able to provide practical support for a budding scientist. Hale's main legacies from his mother appear to have been a love for literature and a lifelong tendency to precarious health, which frequently interrupted his own research and his public work. He held a BS in physics from the Massachusetts Institute of Technology [MIT] (1890) and a dozen honorary doctorates, though no formal Ph.D. By the time of his death, his medals, academy memberships, and other honors occupied 28 lines of small-print text.

By the age of 13, Hale had visited nearby observatories, interviewed astronomers and telescope makers, planned his own astronomy journal, and sent off letters to general-interest magazines offering to write articles on astronomy. **Sherburne Burnham** was sufficiently impressed by young Hale to allow him to assist in observations of double stars, and to tell him about a secondhand 4-in. Alvan Clark telescope, which George persuaded his father to buy in time for Hale to observe a transit of Venus in 1882. Hale soon equipped the telescope with a simple one-prism spectroscope, and by 1888, had a well-equipped shop and a spectrographic laboratory with a 10-ft.-focal-length Rowland concave grating, the foundation of the Kenwood Observatory. The availability of a physics laboratory and instrument shop at the observing facility, and the focus on the use of the spectrograph for the study of the Sun and other stars, became the cornerstones of Hale's approach to astronomy.

Bored by his physics courses at MIT (then called Boston Tech), Hale persuaded **Edward Pickering** to allow him to work on Saturdays at the Harvard College Observatory. For his senior thesis, Hale developed an idea that occurred while he rode a Chicago tram past a picket fence – an instrument that would use the movement of the Earth to draw a slit aperture across the face of the Sun while a photographic plate was moved synchronously over a corresponding slit at the other end of the spectrograph. In this way, he was able to produce an image of the Sun at one specific wavelength, for instance the chromospheric emission by ionized calcium or hot hydrogen gas. Hale named it a spectroheliograph, and used it, with refinements, as his primary research instrument for the study of solar phenomena.

Hale married Evelina Conklin after his graduation from MIT, and took his honeymoon at the new Lick Observatory in California. Although impressed with the new 36-in. refractor, the Crossley reflector, and the remote site, Hale declined an offer to stay at Lick, and returned to Chicago to first do independent research, and later to accept a position at the new University of Chicago, where he began the systematic study of solar flocculi and prominences that culminated in his identification of the magnetic field of sunspots, and later the identification of the polarity of the spots and the reversals of the polarity after each sunspot cycle.

In 1892 he established the journal *Astronomy and Astrophysics* with **William Payne** to provide a forum for the new discipline of astrophysics. Three years later, with Keeler as joint editor, he founded the *Astrophysical Journal*, still the leading journal in the field. When the time seemed ripe to found an American astronomical organization in 1899, Hale insisted that it be called the Astronomical and Astrophysical Society of America; it was only in 1914 that the name was simplified to American Astronomical Society.

Hale was only 24 years old when he learned that 40-in. flint and crown glass blanks for the objective lens of a large refractor had been successfully cast in France for a southern California group that could not follow through on the project. He pursued the funds to build a large refractor, finally convincing the streetcar magnate Charles Tyson Yerkes that he could demonstrate his farsightedness and vision by funding a telescope that would "lick the Lick." Yerkes balked when he discovered that the observatory he was funding would be at a remote location on the shore of Lake Geneva in Wisconsin, but Hale persisted, and the completed Yerkes telescope became the largest functional refractor ever built. The observatory included first-rate instrument and optical shops, physics laboratories, and darkrooms. But the strain of securing the funds and organizing and supervising the construction of a large facility in a remote location unnerved Hale. The headaches and other nervous symptoms he had experienced in childhood returned, sometimes with such severity that he had to stay home in bed.

Even before the Yerkes refractor was complete, Hale realized that future spectroscopic research on the Sun, stars, and nebulae would require specialized long-focus solar telescopes and a large and versatile reflector at a cloud-free location with superb seeing. Hale found a site for the new telescopes at Mount Wilson, a mountaintop reached by a mule trail and blessed with superb seeing above the Los Angeles, California, basin. He persuaded his father to contribute a 60-in. blank, the largest plate glass disk the French foundries could cast in a single pour and gave **George Richey**, a perfectionist and martinet, the task of figuring the mirror while Hale endeavored to raise the funds for mounting and construction of an observatory at Mount Wilson.

Hale ultimately secured the funding from the new Carnegie Institution, but the aggressive pace of his own research, the demands of fund-raising and supervision of a major project on a remote mountaintop, and the administration of both Yerkes and a major observatory at Mount Wilson took a further toll on his temperament. By 1908, a year in which he was nominated for a Nobel Prize, used one of the solar telescopes on Mount Wilson to identify the Zeeman effect as evidence of a magnetic field in a sunspot, and the great 60-in. telescope saw first light—his symptoms were sometimes so severe that Hale would have to retire to a dark, quiet room, or retreat to a sanatorium, missing events of great personal import such as the meeting of the International Solar Union (which he had helped to found) at Mount Wilson.

The successful and versatile 60-in. telescope was followed by the 100-in. Hooker telescope. The problems of getting a French foundry to successfully cast the huge plate glass disk, the obstreperousness of Richey, and the engineering and fund-raising challenges aggravated Hale's delicate mental state until the recurring, incapacitating symptoms were joined by doubts and severe depression that refused to respond to the contemporary treatments of travel, rest, and sanatorium care. Hale persisted, and the 100-in. telescope saw first light in 1917.

Beginning in 1920, Hale gradually withdrew from the active direction of the many institutions he had established and administered. He retired from the directorship of Mount Wilson, and began spending more and more of his time at the private solar laboratory he had built in Pasadena, decorated with Egyptian themes from his travels, and equipped with both a spectroheliograph that he could use to continue his solar research and a quiet room with blackout curtains where he could flee the recurrent bouts of depression. By the mid-1920s, he was using his contacts in the worlds of foundations and industry to propose and secure an unprecedented six-million dollar funding for a 200-in. telescope. Hale's vast "Old Boy Network," in an era when there were no formal mechanisms to promote the cooperation of academic, industrial, and government entities, enabled him to recruit companies like General Electric, Corning, and Westinghouse to the project, and to assemble a remarkable staff of engineers, opticians, and designers to design and build complex new control and mounting systems and to explore the use of new materials like fused quartz and Pyrex for the telescope mirrors. **John Anderson** served as executive officer of the Observatory Council responsible for the 200-in. Palomar telescope, but Hale remained active in the project, and the council met at Hale's solar laboratory as a neutral facility that could draw on both Caltech and the Carnegie observatories. Only in the mid-1930s did Hale's health deteriorate to the point where Max Mason from the Rockefeller Foundation took over the chairmanship of the Observatory Council.

Hale died within 10 years of the initiation of the 200-in. telescope project, and 10 years before the completion of the telescope, which was named after him.

The George Ellery Hale Papers were edited by Daniel Kevles and produced in microfilm edition at the California Institute of Technology. There are also significant collections of Hale's papers and correspondence in the Carnegie Observatories and Mount Wilson archives at the Huntington Library and in uncataloged cartons in his former Pasadena solar laboratory.

Ronald Florence

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Hall, Asaph

Born **Goshen, Indiana, USA, 15 October 1829**
Died **Annapolis, Maryland, USA, 22 November 1907**

Asaph Hall, master of positional astronomy and discoverer of the satellites of Mars, was in many respects a self-taught scholar who rose to the highest ranks of the American astronomical and scientific communities.

The Hall family arrived in the Massachusetts Bay Colony around 1630. The astronomer's grandfather, named Asaph Hall, participated in the capture of Fort Ticonderoga during the American Revolution. His father, also named Asaph Hall, was a Connecticut manufacturer of wooden clocks. He sold these timepieces throughout the southern states. His untimely death, when Asaph was only 13, left the family in financial straits. Hall's mother, Hannah, then attempted to operate a commercial cheese factory – a highly unusual occupation for a woman of her time. After her 3 years of failure, Asaph was forced to quit school and was put to work as a carpenter's apprentice. Athletic and over 6 ft. tall, he earned his livelihood in this way for 3 years, and for 6 more as a journeyman carpenter. Throughout this time, Hall continued to teach himself science and mathematics from books in his father's library or elsewhere.

In 1854, at the age of 25, Hall decided to continue his higher education. Having learned of an arrangement where students could pay for tuition and board by manual labor, he moved to McGrawville, in upstate New York, and enrolled in Central College. Few of Hall's fellow students in this pioneering work-study program cared much for the classical education he sought, but his mathematics teacher, Angeline Stickney, then in her senior year at the college, shared both his ideals and his determination. After her graduation, the two married and immediately moved to the new observatory (opened in 1855) at the University of Michigan. There, Hall began to study astronomy under director **Franz Brünnow**, who had previously held the post of assistant to the chief astronomer at the University of Berlin Observatory.

After only 3 months, lack of means forced the couple to take posts as teachers at Shalersville Institute in Ohio. One year later, they moved to Cambridge, Massachusetts, then the center of contemporary astronomical research in the United States. Hall asked for, and received, a low-paying position at the Harvard College Observatory. He distinguished himself by a willingness to work long hours, some of it on almanac computations for extra pay, and others devoted to continuing study. Tutored in German by his wife, Hall read advanced astronomy texts by Brünnow and **Carl Gauss**, and began to publish research articles in **Benjamin Gould**'s *Astronomical Journal*.

Because of his Confederate sympathies, commander **Matthew Maury**, the first director of the US Naval Observatory in Washington, resigned and was replaced by captain **James Gillis**. This personnel change yielded several other vacancies, one of which, as assistant astronomer, Hall obtained in 1862. The New Englander found the southern climate stifling, the small increase in pay rendered less valuable by wartime inflation, and the effort to care for wounded friends exhausting. In 1863, however, thanks to an application submitted by Hall's wife on his behalf and without his knowledge, he was promoted to full professor of mathematics at the Naval Observatory.

Federal investment in science increased rapidly after the Civil War. In 1870, the US Congress authorized construction at the Naval Observatory. It came to house a 26-in. refracting telescope produced by Alvan Clark & Sons, then the largest instrument of its kind in the world. During a particularly favorable opposition of Mars in 1877, Hall began a search for unknown satellites of the planet. His own theoretical work had suggested that he should look close to the planet's surface, because more distant bodies would be drawn away by the gravitational pull of the Sun. "The chance of finding a satellite appeared to be very slight," he wrote, "so that I might have abandoned the search had it not been for the encouragement of my wife." Hall's diligence was rewarded with the discovery of Deimos on 11 August and Phobos on 17 August.

Hall had likewise known **Simon Newcomb**, chief astronomer of the Naval Observatory, since his days in Cambridge; the two had arrived at the observatory together during the Civil War. Newcomb sponsored Hall's election to the elite National Academy of Sciences in 1875, chiefly for his initiative and industry in leading three solar eclipse expeditions. For his discovery of the Martian satellites, Hall was awarded the Lalande Prize of the French Academy of Sciences and the Gold Medal of the Royal Astronomical Society.

Newcomb and Hall undertook a program of improving the precision of planetary satellite orbits, with Hall providing positional measurements of not only the satellites of Mars but also those of Saturn, Uranus, and Neptune. In 1893, Hall received the Arago Medal of the French Academy of Sciences in recognition for this work, and in 1896 was named *Chevalier* (knight) in the French Legion of Honor.

No friend of the newer methods of astrophysics, Hall anticipated the day "when the novel and entertaining observations with the spectroscope have received their natural abatement and been assigned their proper place." Nevertheless, Hall exercised leadership roles within the National Academy and the American scientific communities. Of the former, he was secretary for 12 years and vice president for 6; he was elected president of the American Association for the Advancement of Science in 1902. Hall acted as an advisor to astronomers seeking election to the academy, exercising both diplomacy and tact. His priorities appear to have sided with an increased representation of all astronomers in the academy, rather than favoring a partisanship of either tendency within the discipline.

For 10 years after his mandatory retirement from the Naval Observatory, Hall was an associate editor of the *Astronomical Journal*. For 5 of those years, he taught celestial mechanics at Harvard. In 1894, Hall proposed a modification of Newton's law of gravitation to account for the anomaly in the precession of Mercury's orbit, an idea also favored by his USNO colleague Newcomb. Eighteen years later, **Albert Einstein** presented that anomaly as evidence for his General Theory of Relativity.

Michael Meo

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Hall, John Scoville

Born **Old Lyme, Connecticut, USA, 20 June 1908**
Died **Sedona, Arizona, USA, 15 October 1991**

John Hall was noted as an observational astronomer and as director of the Lowell Observatory. He was the son of Nathaniel Hall, a farmer and candy manufacturer. After graduating with an AB degree from Amherst College in 1930, Hall earned a Ph.D. at Yale University, studying with **Frank Schlesinger**, **Dirk Brouwer**, and Jan Schilt. In 1933, Hall defended a thesis on near-infrared stellar photometry. Hall was the first to cool a photocell with dry ice to reduce the dark current, permitting more sensitive astronomical measurements. He was also the first to use a photocell to scan stellar spectra, and the first to use a wire grating to isolate spectral regions for relative photoelectric spectrophotometry. Working with **Albert Hiltner**, Hall discovered the polarization of starlight by the interstellar medium, a topic that occupied much of his research agenda for the remainder of his life as he studied the polarization of light from galaxies, stars, planets, and the Earth's Moon.

During World War II, Hall was involved with radar research at the Massachusetts Institute of Technology, publishing a book on *Radar Aids to Navigation* in 1947 as a result.

In 1948, Hall became a division director at the US Naval Observatory in Washington, continuing his work on polarization with the 40-in. Ritchey–Chrétien telescope. On his recommendation, that instrument was relocated to Flagstaff, Arizona, to find more favorable light levels and seeing conditions. Hall moved with the telescope and remained in Flagstaff in several different capacities for the rest of his life.

Appointed director of the Lowell Observatory in 1958, Hall is widely credited with the restoration of that institution, which had declined steadily over the previous decades. His reinvigoration efforts resulted in a joint venture with the Perkins Observatory of Ohio Wesleyan University and the relocation of the 69-in. Perkins reflector from Delaware, Ohio, to a dark site on Anderson Mesa, south of Flagstaff. Lowell Observatory also acquired a new 42-in. reflecting telescope for the Anderson Mesa site. In addition to acquiring new telescopes for the Lowell Observatory, Hall facilitated the development of the Planetary Research Center at the observatory under National Aeronautics and Space Administration [NASA] sponsorship, expanded a well-qualified staff, attracted numerous visiting staff astronomers and students from Europe, and strengthened the Lowell Observatory's standing with the local community.

Hall was active in the leadership of the American Astronomical Society, serving as a vice president from 1963 to 1965. As a vice president of the American Association for Advancement of Science [AAAS], Hall also chaired the AAAS Astronomy Section in 1967. He was elected president of International Astronomical Union [IAU] Commission 16, and also served as vice president of IAU Commission 9. Hall served on the National Academy of Sciences space sciences board from 1967 to 1970, while serving in a similar capacity for the NASA lunar and planetary missions board from 1967 to 1971. He was awarded honorary doctorates by Amherst College, Ohio Wesleyan University, and Northern Arizona University.

Hall married Ruth Chandler, whom he met at Yale. They raised two children. An athlete and sailing enthusiast, Hall was a tennis player for most of his life.

Thomas R. Williams

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Halley, Edmond

Born **London, England, 8 November 1656**
Died **Greenwich, England, 25 January 1742**

Edmond Halley had an extraordinary range of scientific interests and made significant contributions to many of them including stellar astronomy, the scale of the Solar System, navigation and geophysics, mathematics, and the motions of comets. To some extent, the genius of Halley was overshadowed by the brilliance of his colleague, **Isaac Newton**. It was Halley who persuaded Newton to finish his masterwork, the *Principia*, and then paid for the publication costs himself.

The eldest son of a well-to-do London landowner, salter, and soapmaker of the same name, young Edmond benefited from tutoring at home before attending Saint Paul's school. In 1673, Halley entered Queen's College, Oxford. Three years later, he traveled to the island of Saint Helena with the intention of supplementing the Northern Hemisphere star catalogs of **John Flamsteed** and **Johannes Hevel** with one from the Southern Hemisphere. In 1678, Halley returned to England and presented the king with a map of the southern stars. By royal command, he was awarded the MA degree by Oxford University although he had not fulfilled the residency requirement. During the same year, Halley was elected as a fellow of the Royal Society of London but resigned in 1685 when he was elected clerk of that society, a position he held until 1699. In 1696, as a result of a recoinage within England, Halley became deputy controller of the Mint at Chester for 2 years. For the 3 years, 1698–1701, he undertook three voyages to chart magnetic variations and investigate tidal phenomena. In 1702 and 1703, Queen Anne sent Halley on diplomatic missions to Europe to advise Emperor Leopold of Austria about the fortifications of seaports on the northern shores of the Adriatic. In 1704, he obtained the Savilian Chair of Geometry at Oxford and in 1720 Halley was appointed Astronomer Royal. In 1682, the same year that the comet that would one day bear his name returned, he married Mary Tooke. Of his three children, his two daughters, Katherine and Margaret, survived him. His only son, Edmond, predeceased him by 1 year.

In stellar astronomy, Halley is credited as being the first to construct a star catalog for those stars observable in the Southern Hemisphere and the first to establish that stars change their positions with time. In 1676, before finishing his work at Oxford, the young Halley set sail for Saint Helena, off the western coast of Africa. Despite poor weather conditions, Halley managed to make the necessary observations and compile a star catalog of 360 stars, which was quickly published when he returned in 1678. Halley's catalog not only recorded the absolute positions of the stars on the celestial sphere but also their interstar angular distances so that future star catalogs could be easily updated if improvements were made for some stellar positions. By comparing the positions of bright stars as compiled by **Ptolemy** and those compiled in more recent times, Halley concluded that some current star positions were significantly different from those given by Ptolemy even when the effects of precession and observational errors were taken into account. Although Halley was only able to establish the so called proper motions of three bright stars, Arcturus, Procyon, and Sirius, he correctly noted that other dimmer (and probably more distant) stars also had proper motions but that the amount was undetectable.

In studying the scale of the Solar System, Halley developed plans for observing the transits of Venus across the face of the Sun to determine the solar parallax, or the distance between the Sun and the Earth. Although this idea had been suggested by **James Gregory** in 1663, Halley developed the idea into an observing plan and called attention to the fact that the next opportunities would occur in 1761 and 1769. Observers were to note the time at which Venus first entered into the Sun's disk and the time when it first departed the solar disk. When compared with similar timing measurements taken by other observers located at different observing sites, the distance to Venus could be determined. By Kepler's third law, this one absolute distance measurement could be used to determine the scale of the Solar System since the relative distances of the planets from the Sun were already known. Extensive international observing campaigns were organized in 1761 and 1769 to make the necessary measurements. Although the observations were made somewhat imprecise because the circular images of Venus near the Sun's limb were distorted by atmospheric seeing effects, the campaign did ultimately succeed in determining several estimates for the Sun's distance including a few that provided a correct solar distance of about 93 million miles.

Halley also made contributions to navigation and geophysics. In 1683 and 1692, he published his views on the Earth's magnetic field. Halley suggested that the Earth's magnetic field is generated by an inner magnetic core with its north and south magnetic poles and by an outer magnetic shell with its own north and south magnetic poles. The core and the shell then had slightly different rates of diurnal rotation so that one could account for the observed variations in the Earth's magnetic field. The space between the core and the shell was filled with "effluvium," and in a subsequent paper published in 1716, auroral displays were explained by luminous effluvium that had escaped and was controlled by the Earth's magnetic field. In an effort to solve the problem of determining longitude at sea, Halley investigated terrestrial magnetism and the extent that a magnetic compass needle would vary from the meridian direction in response to local magnetic fields at particular locations on the Earth's surface. In 1698–1700, Halley was commissioned as a naval captain and took his ship, the *Paramore*, across the Atlantic to map out the magnetic variations at various locations. By connecting equal points of magnetic variation, Halley established the first charts showing magnetic variations, which he hoped would be useful to subsequent sailors for determining longitude. Unfortunately, the magnetic variations do not show systematic changes with longitude, nor do they remain constant with time. While the use of these charts for the determination of longitude was impossible, they were the first examples of isogonic lines.

In an effort to date the Earth, Halley suggested that the salinity in the Earth's waters was increasing and by measuring the current level of salinity and approximating the rate of increase he arrived at a date that was far too long to be compatible with Biblical evidence and too short to conclude that the Earth was eternal. This is but one example of Halley's trust in science over religious faith – an attitude that was not popular with many of his contemporaries and an attitude that likely prevented his obtaining the Savilian Chair of Geometry at Oxford earlier than he infact did.

Halley's papers on pure and applied mathematics included those on higher geometry, the computation of logarithms and trigonometric functions, as well as the trajectories of cannon shot and the focal lengths of lenses. He was also the first to suggest the use of mortality tables as the basis for determining annuities. Halley's interest in mathematics extended to historical works and in 1705, together with **David Gregory**, Halley embarked upon a translation of the work *Conics* by the ancient Greek, **Apollonius**. However, 3 years later, Gregory died and Halley carried on alone. Since the works in the original Greek were not available, Gregory and Halley were forced to use incomplete Arabic translations. Halley not only translated the known work into Latin, but also by using fourth-century comments by the mathematician **Pappus**, managed to restore the eighth section that was not available in Arabic translations. Earlier, Halley completed a translation from Arabic into Latin of *De Sectione Rationis* by Apollonius, work that had been started by Edward Bernard.

Halley is best remembered for his study of comets. Just prior to the publication of his *Principia* in 1687, Isaac Newton had worked out a semigraphical technique for computing the orbits of comets using angular position observations of the comet with respect to neighboring background stars. Newton applied his method only to the comet of 1680 and computed a parabolic orbit for this comet. It was Halley who suggested to Newton in 1687 that his method should be tried upon the observations of other comets. Eight years later, Halley took up his own suggestion and wrote to Newton, noting his own parabolic orbit for the comet of 1683, his reexamination of the orbit for the comet of 1680, and his suspicion from their orbital similarities that the comets seen in 1531, 1607, and 1682 were one and the same object. Halley correctly attributed the unequal time intervals between the three apparitions to the perturbative effects of Jupiter.

When Halley's masterwork, *A Synopsis of the Astronomy of Comets*, was finally published in 1705, it was only a 16-page pamphlet. Much of the important information is contained in a single table giving parabolic orbital elements for 24 comets observed from 1337 through 1698. Halley had used a modified version of Newton's method that produced parabolic orbits but he was of the opinion that their true paths were elongated ellipses. The similarity between the orbital elements for those comets seen in 1531, 1607, and 1682 led Halley to suggest that this comet would return again in 1758. It was not until his posthumous *Astronomical Tables* were published in 1749 and 1752 that the prediction was revised to late 1758 or early 1759. A specific perihelion passage time prediction of mid-April 1759 would be left to **Alexis Clairaut** who finished his work just before the comet was recovered on 25 December 1758. Although in Halley's time, his cometary prediction was not mentioned prominently when his achievements were discussed, the successful recovery of comet Halley in late 1758 and its perihelion passage on 13 March 1759 caused this comet to be named after Halley (IP/Halley) and this first successful prediction for a comet's return was used to glorify the Newtonian theories that made it possible.

Donald K. Yeomans

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Halm, Jacob Karl Ernst

Born **Bingen, (Rheinland-Pfalz, Germany), 30 November 1866**
Died **Stellenbosch, South Africa, 17 July 1944**

German–South African observational astronomer Jacob Halm may have been the first to suggest a correlation between the masses of stars and their luminosities. He received his schooling in Bingen, Germany, and spent 4 years at the universities of Giessen, Berlin, and Kiel, finally receiving his Ph.D. for work in spectroscopy, with other work in mathematics and the theory of tides. While in Kiel, Halm came into contact with **Carl Krüger** of Strasbourg Observatory, editor of the oldest astronomical journal, *Astronomische Nachrichten*, with which Halm assisted for some time.

In 1889, upon the recommendation of Krüger, Halm was appointed to a position at Strasbourg, working primarily in positional astronomy. He worked in support of the Strasbourg zone of the *Carte du Ciel*, roughly one-third of the zone being completed before Halm moved on in 1895 to become an assistant to **Ralph Copeland**, the Astronomer Royal for Scotland at the newly erected Royal Observatory in Edinburgh. Initially, Halm assisted in mounting and adjusting the instruments, later using them to measure accurate positions of stars and comets for determination of orbits of binary stars and comets. From 1901 to 1906, he undertook extensive monitoring of the differential rotation of the Sun, for which he was awarded the Brisbane Gold Medal of the Royal Society of Edinburgh. The observations filled a gap between the Uppsala observations carried out by **Nils Dunér** ending in 1901 and those of **Walter Adams** at Mount Wilson, California, which began in 1906.

Halm was selected for the post of chief assistant (to **Sydney Hough**) at the Cape Observatory in South Africa, a post that he held until 1926, when he retired to Stellenbosch. He continued to give advanced astronomy lectures at the university there for many years. Much of Halm's work in South Africa involved measuring and interpreting radial velocities of stars, which led to orbits of spectroscopic binaries and (with Hough in 1909/1910) to the interpretation of the velocity distributions as being due to star streams of the sort suggested by **Jacobus Kapteyn**. He continued work in positional astronomy, attempting to measure the geocentric parallax of Mars in order to determine the length of the Astronomical Unit (1924). His result was in good accord with that determined earlier by Hough from some of their radial velocity data, though both were too small by amounts larger than their own estimated errors.

Halm also worked in photometry, establishing a standardized magnitude system for the Cape zone of the *Astrographic Catalogue* (*Carte du Ciel*) in the form of a South Polar Sequence. He interpreted some of the magnitude measurements as implying that there might be a narrow band of absorbing material along the galactic Equator and in 1917 set an upper limit of 2.1 mag/kpc to the amount. A typical modern value is about 1 mag/kpc in the visual band. The suggestion of a mass–luminosity relation for stars also came from his Cape work on binary stars (1911). In connection with Halm's earlier career, one of the key stars in the relationship is the low-mass visual binary Krüger 60.

Halm was active in encouraging interest in astronomy in South Africa and was president of its astronomical society in 1924 and 1934. He resigned his fellowship in the Royal Astronomical Society, dating from 1906, in 1940, when Jan Christiaan Smuts brought the Union of South Africa into World War II on the side of the Allies. (Halm had already experienced a good deal of unpleasantness as a German in a British colony during World War I.) He was particularly interested in encouraging amateur astronomers, and his booklet, *The Universal Sundial*, helped them to construct sundials for checking clocks before time signals could be broadcast to the more remote parts of the country. Halm had married Hanna Bader of Basle in 1894, and they had one son and two daughters.

Hartmut Frommert

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Hanbury Brown, Robert

➔ **Brown, Robert Hanbury**

Hansen, Peter Andreas

Born **Tondern (Tønder, Denmark), 8 December 1795**
Died **Seeberg near Gotha, (Thuringia), Germany, 28 March 1874**

Self-taught astronomer Peter Hansen presented the most complete theory of the Moon's orbit that was understood in his day and solved the long-standing puzzle of the Moon's secular acceleration. Hansen, the son of a goldsmith, was unable to secure a formal education and became apprenticed to a clockmaker in Flensburg. Entirely on his own, he studied foreign languages and mathematics. Hansen first became a voluntary assistant to **Heinrich Schumacher** in 1820 and conducted mainly geodetic work. Between 1821 and 1825, he served as Schumacher's assistant at the Altona Observatory and aided publication of the *Astronomische Nachrichten*, all the while developing his mathematical talents in celestial mechanics. In 1825, Hansen was chosen as director of the private observatory of the Duke of Mecklenburg at Seeberg (succeeding **Johann Encke**). He retained this position for the remainder of his life. Among Hansen's students was the Scandinavian astronomer **Johan Gyldén**.

Hansen's first significant work explored the mutual perturbations of Jupiter and Saturn upon one another, an accomplishment that netted him a prize from the Royal Academy of Sciences in Berlin and the Gold Medal of the Royal Astronomical Society. But his principal achievement concerned his theory of the Moon's

orbit. As far back as 1787, the French master of celestial mechanics, **Pierre de Laplace**, had suggested that the secular acceleration of the Moon might be explained by slow oscillations of the eccentricity of the Earth's orbit. However, it was later shown that such a mechanism could only account for about half of the observed acceleration.

Hansen's solution to the puzzle relied in large part upon the reduction, spearheaded by Astronomer Royal **George Airy**, of some 8,000 observations of the Moon conducted at the Greenwich Observatory between 1750 and 1830. From his analysis of Airy's data, Hansen recognized two inequalities in the Moon's longitude that were related to the gravitational attraction of Venus upon the Earth–Moon system. In the words of historian Robert Grant, these two factors "completely accounted for the errors in the tables, which had so long perplexed the astronomers and mathematicians of Europe." Hansen also identified two inequalities in the Moon's latitude. His newer tables of the Moon's motion were published in 1857 at the expense of the British Admiralty (adopted for the *Nautical Almanac*). For the second time, Hansen was awarded the Gold Medal of the Royal Astronomical Society. A younger rival, the Canadian-born mathematician and astronomer **Simon Newcomb**, referred to Hansen as "the greatest master of celestial mechanics since Laplace."

Ironically, it was Hansen's spurious calculation (1854) of the figure of the Moon that attracted general interest. He deduced that the Moon's center of gravity was not located at its geometric center, but was displaced *farther* from the Earth (whereas the opposite condition is true). His conclusion that the Moon's farside might possess a more substantial atmosphere was featured in Jules Verne's science-fiction romance, *Around the Moon* (1865).

Thomas A. Dobbins and *Jordan D. Marché, II*

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Hansteen, Christopher

Born **Christiania (Oslo, Norway), 26 September 1784**
Died **Christiania (Oslo, Norway), 11 April 1873**

Christopher Hansteen was a Norwegian astronomer and geomagnetist. He entered Copenhagen University in 1802 to study law. However, influenced by Hans Christian Ørsted, Hansteen's interests turned to astronomy, physics, and mathematics. From 1806 to 1813 he served as a teacher of mathematics at the secondary school in Hillerød, near Copenhagen. In 1814 he was appointed lecturer at the University of Christiania and promoted to professor in 1816. He retired in 1861. In 1814, Hansteen married Johanne Cathrine Andrea Borch (1787–1840) from Sorø in Denmark. They had six children.

In Christiania, Hansteen arrived at a university – established only 3 years earlier – starting virtually from scratch, and the newly independent state of Norway was not much better off. Building and developing the new nation became the predominant task for the university, and Hansteen contributed with great energy. Within the university, he dealt with a broad range of disciplines – physics, mathematics, mechanics, geodesy, astronomy, and meteorology. Outside the university, his abilities were also extensively required. Through his 55-year-long leadership of the Geographical Survey of Norway, the country obtained a firm geodetic network. He lectured at the military academy for 23 years, and worked out a system of weights and measures for the new state, to mention a few of his activities. He also clearly saw the need for general education and was instrumental in publishing a popular science journal, to which he was a frequent contributor.

Formally, Hansteen was professor of applied mathematics. Quite soon, however, he was regarded as professor of astronomy.

His work as an astronomer also reflected the need of the Norwegian state – provision of correct time and positions from astronomical observations. To this end, he had to observe from provisional shelters for several years before a proper observatory in Christiania was inaugurated in 1833. His astronomical papers are mainly found in *Astronomische Nachrichten*, and his best achievement probably is a simple method for time determination by observing a star in the vertical of the Pole star. From his very first year at the university, Hansteen was given the task of calculating and editing the official almanac of Norway, and he kept doing so for 46 years.

Today, Hansteen is remembered primarily as a geomagnetist. He took interest in this field during his years in Hillerød, and was, in 1812, awarded a prize by the Royal Academy in Copenhagen for an essay on the problem "can the magnetic field of the Earth be described by one magnetic axis or do we need more?" On the basis of this, he published his main work in 1819: "Untersuchungen über den Magnetismus der Erde" (Research on the Earth's magnetism). Here, Hansteen summarized the state of geomagnetism at the time, presented tables of most geomagnetic observations made so far, and drew maps of all three components at several epochs. Finally he worked out a mathematical model with two magnetic axes fitted to the observations. He thus revived the four-pole theory advocated by **Edmond Halley** 100 years earlier. This work of Hansteen's certainly was one of the reasons why **Carl Gauss** took interest in geomagnetism, and in 1838, he replaced Hansteen's simple model of the field with the elegant description based on spherical harmonics.

Hansteen was a keen and conscientious observer and missed no opportunity to add new points to the geomagnetic maps. The highlight of his magnetic mapping was his expedition to Siberia during the years 1828–1830. The goal was to locate the assumed secondary pole in East Siberia. In this, however, he failed. Hansteen, by 1824, developed what is called "Hansteen's apparatus" for relative measurements of magnetic field strength; the oscillation of a magnet horizontally suspended from a long silk thread was used to provide a measure of the horizontal component of the field. This simple instrument became very popular and was used for decades in geomagnetic mapping. Gauss and W. E. Weber in 1833 incorporated this oscillation experiment as part of their method for absolute determination of the field. Hansteen was an active participant in the Göttinger Magnetische Verein (Göttingen Magnetic Union) from 1836 to 1842 for international coordination of geomagnetic observations, and he established, in 1841, the Christiania Observatory as a magnetic observatory of international standard.

The records of Hansteen's life and work are scattered on several short papers, almost exclusively in Norwegian. A comprehensive biography is still to be written, as is a bibliography. His numerous papers are spread around in German, Belgian, British, and Scandinavian journals.

Truls Lynne Hansen

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Harding, Carl Ludwig

Born **Lauenburg, (Schleswig-Holstein, Germany), 29 July 1765**
Died **Göttingen, (Germany), 31 August 1834**

Carl Harding is best remembered for his discovery of the third asteroid in 1804, which he found while preparing an ecliptic star atlas. He was the son of Carl Ludwig Harding, a protestant pastor, and his wife Christine Louise (*née* Engelbrecht).

Following his studies of theology, mathematics, and physics at Göttingen (1786–1789), Harding became a private tutor. In 1796, he joined the household of **Johann Schröter** at Lilienthal, near Bremen. Harding was soon involved in the widespread observational activities of his patron and, from 1800, held the position of observatory inspector. In 1805, he became a professor of practical astronomy at Göttingen. His promotion to full professorship followed in 1812. Harding was married and had one daughter.

Physical observations of the planets had constituted the main activity of Schröter's Lilienthal Observatory. But with the discovery of (1) Ceres, positional astronomy became a new and important field of activity. In 1800, the Vereinigte Astronomische Gesellschaft was founded at Lilienthal and established a European network of observers charged with mapping the ecliptic zone of the sky. Harding set to work on this project, and as a consequence, discovered the asteroid (3) Juno in 1804. His careful survey of the sky resulted in 27 maps comprising the *Atlas novus coelestis* (1808–1823), which plotted roughly 60,000 stars. This first-of-a-kind atlas was drawn without the traditional constellation figures; it remained a basic tool of astronomers until it was superseded by the *Bonner Durchmusterung* in 1852.

At Göttingen, Harding later joined in another mapping project, the *Akademische Sternkarten*, edited by **Johann Encke** at Berlin. Harding's contribution (hour XV in right ascension) was completed in the first year of the program (1830). In addition, he conducted observations of the planets, comets, variable stars, and lunar occultations. He independently discovered four comets, none of which is now named for him (C/1813 G1, C/1824 O1, C/1825 P1, and C/1832 O1); he recovered comet 2P/Encke in 1825 (the second observed return *via* successful prediction of this comet). Harding also performed longitude determinations and collected relevant weather data. His results and discoveries were published regularly in **Johann Bode**'s *Astronomisches Jahrbuch*, **János von Zach**'s *Monatliche Correspondenz*, and **Heinrich Schumacher**'s *AstronomischeNachrichten*.

Wolfgang Kokott

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Haridatta I

Flourished **(Kerala, India), 683**

Haridatta I was an acclaimed astronomer of Kerala, the narrow strip of land situated on the west coast of south India, which, from early times, was a hub of astronomical activity. It was Haridatta I who promulgated the Parahita system of astronomy, by rationalizing the astronomical system enunciated in the *Āryabhaṭīya* of **Āryabhaṭa I**. Remarkably, the Parahita system is followed even today in Kerala, for the preparation of almanacs and the determination of auspicious times for religious functions. (An astronomer who flourished in Rajasthan in the 17th century, and called Haridatta II by historians, bears no relationship to the subject of this sketch.)

Little is known about the personal details of Haridatta I except what is mentioned in his works, namely that he was a devotee of God Hari and was a follower of the Brāhma School of astronomy, one of four principal schools active during the Hindu classical period (late 5th to 12th centuries).

Haridatta I promulgated his new system through two works, the *Mahāmārganibandhana* (The Book of Extensive Full-Fledged Astronomy), which is now lost, and the *Grahacāranibandhana* (The Book on the Motion of the Planets). The Parahita system was proclaimed on the occasion of the 12-year Mahāmaham festival at Tirunavay in north Kerala, in 683. Reasons for the introduction of the Parahita system are recorded in two other astronomical works from Kerala, the *Dṛkkaraṇa* of **Jyeṣṭhadeva**, and the *Sadratnamālā* of Śaṅkara Varman. When the planetary calculations derived from the system of Āryabhaṭa I were found to deviate from the planets' actual positions, corrections were sought among the computations embraced by the Parahita system. These corrections, called *Bhaṭasaṃskāra* (Corrections to Āryabhaṭa), were also called *Śakābdasaṃskāra* (Correction Set to the Śaka Year, from 444).

Among Haridatta I's other innovations were the adoption of a facile letter-numeral connotation for numbers called the *Kaṭapayādi*, which rejected the cumbersome letter-connotation usage of Āryabhaṭa I, and a unique system of graded trigonometric tables that facilitated the computation of planetary positions. These and other minor innovations rendered astronomical calculations easier and made the Parahita system extremely popular long after Haridatta I's death.

Ke Ve Sarma

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Harkness, William

Born **Ecclefechan, (Dumfries and Galloway), Scotland, 17 December 1837**

Died **Jersey City, New Jersey, USA, 28 February 1903**

At the United States Naval Observatory [USNO], William Harkness reduced the USNO photographic observations of the 19th-century transits of Venus, producing the only valid solar parallax based on that technique. He carried out research in positional astronomy, photography, spectroscopy, and instrumentation design.

Harkness was the son of Reverend Dr. James Harkness, physician and Presbyterian minister, and Jane (*née* Weild) Harkness. The family immigrated to the United States from Scotland in May 1839, settling in New York City, then in Fishkill, New York. Harkness attended the Chelsea Collegiate Institute in New York City and private schools in Fishkill Landing and Newburgh. He entered Lafayette College, Easton, Pennsylvania, in 1854, but transferred to Rochester University in 1856 when his family moved to Rochester, New York. Harkness graduated in 1858 with an A.B. degree, then worked as a legislative reporter, first for the Albany, New York, *Atlas and Argus*, then in 1860 for the Harrisburg, Pennsylvania, *Daily Telegraph*. He returned to Rochester and received his M.A. degree in 1861 and ultimately an LL.D. in 1874.

Harkness studied medicine at the New York Homeopathic Medical College and obtained an M.D. degree in 1862, after which he served as a surgeon in the Union Army during several major battles of the Civil War. In 1862, he was appointed an aid at the USNO and, in the following year, a professor of mathematics in the navy. During his service on the *Monitor*-style warship *Monadnock* from 1865 to 1866, Harkness made an exhaustive study of terrestrial magnetism and the influence of iron armor on the behavior of the compass. His report was published by the Smithsonian Institution in 1871.

Harkness was attached to the Hydrographic Office of the United States Coast Survey in Washington, DC, from October 1866 until October 1867, when he was transferred to the Naval Observatory. There, he pursued a lengthy career in astronomy. He was appointed astronomical director of the Naval Observatory in 1894 and director of the Nautical Almanac Office in 1897. Harkness held both posts until his retirement in 1899. He was elected vice president of the American Association for the Advancement of Science in 1881 and 1885, and its president in 1893.

In 1871, Harkness was appointed one of the original members of the United States Transit of Venus Commission, charged with planning and coordinating American observations of the 9 December 1874 and 6 December 1882 transits. By timing the passage of Venus across the Sun's face, astronomers hoped to better determine the solar parallax, and from that to calculate an improved value of the astronomical unit, the average distance between the Earth and Sun. Harkness developed most of the instruments, plus the observation and reduction techniques used by the transit parties. For the 1874 transit, Harkness employed the relatively new technology of wet-plate photography.

A disagreement arose between Harkness and influential commission members **Simon Newcomb** and **Edward Pickering**, as to the accuracy of the photographically determined astronomical unit. Nevertheless, Harkness vigorously defended photographic observations of transits even after the German and English teams abandoned them in favor of visual observations. Harkness's 1881 paper, "On the Relative Accuracy of Different Methods of Determining the Solar Parallax," was instrumental in convincing US and French astronomers to continue the use of photography – now the dry-plate process – for the 1882 transit. From the photographic data on both transits, Harkness published what is arguably his most significant contribution to astronomy, *The Solar Parallax and Its Related Constants*. There, he reported a solar parallax of 8.842 ± 0.0118″, equivalent to an astronomical unit of 92,455,000 miles with a probable error of 123,400 miles. He later refined the parallax to 8.809 ± 0.0059″ and the astronomical unit to 92,797,000 miles with a probable error of 59,700 miles.

Among Harkness's other scientific contributions were the discovery of the coronal spectral line K 1474 during observations of the total solar eclipse of 7 August 1869, the invention in 1877 of the spherometer caliper, which was the most accurate device known at the time to determine the figure of the pivots of astronomical instruments, an 1879 paper on the theory of the focal curve of achromatic telescopes, extensive experimentation in the 1880s to improve photographic recording of both the ordinary solar spectrum and the coronal spectrum during eclipses, and improvements to Naval Observatory facilities and observing procedures in the 1890s.

Harkness's correspondence and writings are archived at the USNO, Washington, DC, and the University of Rochester.

Alan W. Hirshfeld

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Haro Barraza, Guillermo

Born **Mexico City, Mexico, 21 March 1913**
Died **Mexico City, Mexico, 26 April 1988**

Mexican astronomer Guillermo Haro is eponymized in the Herbig–Haro objects, small seemingly isolated clouds of ionized gas, whose energy sources were long a mystery, but which are now known to be the points where jets from protostellar objects deposit their energy by interacting with their surroundings. Haro was the son of Ignacio de Haro and Leonor Barraza and used their surnames in the traditional Spanish fashion. Both his marriages ended in divorce. His first wife, Gladys Learn Rojas, assisted with the translation into English of his early scientific papers.

After some courses in philosophy and law at the Universidad Nacional Autónoma de México [UNAM], he was briefly a reporter for the daily newspaper *Excélsior*, but developed an increasing interest in astronomy after a 1937 interview with **Luis Erro**, then director of Tonantzintla Observatory. Haro was appointed to the staff there in 1943, without ever having received any formal degrees in astronomy. Yet Erro arranged for him to work, first, at Harvard College Observatory with **Harlow Shapley**, then at Case Observatory with Jason J. Nassau in 1944, and finally at Yerkes Observatory and McDonald Observatory (1945–1947) with **Otto Struve**. Haro returned to Tonantzintla but was looking for a position outside Mexico (owing to disagreements with Erro) when Salvador Zubirán, rector of UNAM, offered him the directorship of the university's Observatorio Astronómico Nacional at Tacubaya, which he headed from 1948 to 1968.

After reconciliation with Erro, Haro became his successor at Tonantzintla, and the two observatories were eventually (in effect) united under his leadership. In 1951, he founded and initially edited the *Boleín de los Observatorios de Tonantzintla y Tacubaya*. It was during this period that Haro independently discovered and wrote about the "nebulous objects near NGC 1999" found by George Herbig. His most important other research contributions were in the discovery of flare stars in the Orion region (work with **William Morgan** in 1953) and studies of planetary nebulae and of faint blue stars (with **Willem Luyten**). Further transformations of the institutions made him director of what is now called the Instituto Nacional de Astrofísica, Óptica, y Electrónica, and he retired from that position in 1983.

Guillermo Haro made three major sorts of contributions to Mexican and world astronomy. First, he mentored younger astronomers who are now part of the leadership of the community there, including Silvia Torres-Peimbert and Manuel Peimbert.

Second, Haro clearly recognized that neither the Tonantzintla site in the state of Puebla (located there because it was funded by a native son) nor the Tacubaya site was really suitable for modern astronomy, and he spearheaded the effort to locate better sites within Mexican territory and to develop them. The current observatories at San Pedro Mári in Baja California and at Cananea in Sonora are the result of that effort.

Third, Haro alerted the rest of the world to the emergence of serious astronomy in Mexico, becoming the first foreign associate elected to the Royal Astronomical Society from a developing country (in 1959), the first Mexican vice president of the American Astronomical Society (1960–1963), and the first Latin American vice president of the International Astronomical Union (1961–1967). He also contributed to the establishment of the Mexican Academy of Sciences (originally Academia de la Investigación Científica) and served as its president during 1960–1962.

Haro finally received an astronomy degree in the form of an honorary D.Sc. from Case Institute of Technology, and a large number of other awards and honors, from which stand out the Mikhail V. Lomonosov medal. He is commemorated more subtly in the names of astronomical objects that begin HL and PHL, which include a number of faint blue stars, blue galaxies, and quasars. H is Haro, and L is Luyten.

Durruty Jesús de Alba Martínez

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Harper, William Edmund

Born **Dobbinton, Ontario, Canada, 20 March 1878**
Died **Victoria, British Columbia, Canada, 14 June 1940**

William Harper was a spectroscopist and observatory director. He published more orbits of spectroscopic binary stars than anyone in the first half of the 20th century.

After graduating from high school, Harper taught primary school for 3 years before entering the University of Toronto in 1902, where he was the first student in **Clarence Chant**'s new program in astronomy. Harper graduated in 1906 with the Royal Astronomical Society of Canada's Gold Medal, being the first to take that prize. This was followed by an MA in 1907. He was hired in 1906 by the Dominion Observatory, where he joined **John Plaskett**'s team to study spectroscopic binary stars. Harper married Maude Eugenia Hall, 12 May 1909, and they had two daughters, Evelyn and Louella.

Once funding was approved for a 72-in. telescope, Harper traveled through western Canada in the summer of 1913 to assess possible observatory sites, ultimately choosing Victoria. In 1919, he transferred from Ottawa to the new Dominion Astrophysical Observatory, where he was the only other astronomer with Plaskett. In 1924, Harper became the first assistant director of the observatory. When Plaskett retired in 1935, Harper succeeded him as director. Harper fell ill in Stockholm in August 1938 while attending the International Astronomical Union meeting. He was hospitalized in Germany, but moved to Denmark and England as international tensions rose; he was only able to return to work for a few months.

Harper joined the Royal Astronomical Society of Canada as a student, later acting in an executive capacity for the Ottawa and Victoria centers; he was national president (1928–1929). He became a fellow of the Royal Society of Canada in 1924, and was also a fellow of the American Association for the Advancement of Science and a member of the American Astronomical Society. Harper sat on the International Astronomical Union's commissions on radial velocities and spectroscopic parallaxes. The University of Toronto honored him with a doctoral degree in 1935. Harper was well known for his public lecturing, newspaper articles, and dozen years of radio broadcasts on scientific topics.

Harper was a remarkable spectroscopist. With limited equipment at Ottawa, he published 50 papers, mostly on radial velocity measurements and spectroscopic binary star orbits. At Victoria, he worked with R. K. Young on the spectroscopic parallaxes of 1,100, mostly late-type, stars, published in 1924. He later revised his methods to work up the spectroscopic parallaxes of some 700 A-type stars. By the time of his death, Harper had measured some 7,000 plates at Victoria, publishing 100 binary star orbits, one-quarter of all published by that time and a far greater number than any contemporary.

Richard A. Jarrell

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Harriot, Thomas

Born **Oxford, England, 1560**
Died **London, England, 2 July 1621**

Galileo Galilei was not the first to grasp the potential of the telescope for astronomical investigations; in England, Thomas Harriot made the first telescopic sketch of the Moon. Harriot was strongly identified with Sir Walter Raleigh's free-thinking "School of Atheisme" and had once served as Raleigh's onetime mathematical tutor and scientific advisor. Another associate was the poet and dramatist Christopher Marlowe (1564–1593). But unlike his colorful poet-companions, Harriot seems to have been personally reserved and quiet, a perfectionist whose knowledge of mathematics was extensive but who published little during his lifetime.

In 1585, when he was in his early 20s, Harriot accompanied Raleigh as surveyor and cartographer on an expedition to Virginia. Although he planned an encyclopedic account of the New World, he actually produced only "A brief and true report of the new-found land of Virginia," which became widely known through Richard Hakluyt's *Principal Navigations* (1598–1600), a collection of the voyages made by English adventurers like Raleigh.

But these had been the adventures of a younger man. Harriot was already 50 when he first turned a telescope toward the 5-day-old Moon on the evening of 26 July 1609 (5 August). Though magnifying 6×, his "trunke," as he called it, must have been of very poor optical quality, since it showed very little detail. For that matter, Harriot seems to have had very little insight into the true nature of what he was seeing—about as little as was shown on a slightly later occasion by his friend Sir **William Lower**, who used one of Harriot's telescopes to make his own observations of the Moon from Kidwelly in Wales. Lower wrote memorably to Harriot on February 6, 1610 (O.S.).

> According as you wished I have observed the moone in all his changes. In the new I discover manifestlie the earthshine, a little before the dichotomie that spot which represents unto me the man in the moone (but without a head) …. A little after neare the brimme of the gibbous parts like starres, much brighter then the rest and the whole brimme along, lookes like unto the description of coasts, in the dutch bookes of voyages. In the full she appeares like a tarte that my cooke made me the last weeke. Here a vaine of bright stuffe, and there of darke, and so confused lie al over.

Although Galilei easily had the finest telescopes available at the time, we must not allow this fact to obscure Galilei's uncanny talent as an observer. The contrast between Galilei's decisive results and Harriot's and Lower's early attempts demonstrate Galilei's genius as an observer. Galilei was certain that the Moon was "sprinkled over with prominences and depressions," and was measuring the heights of lunar peaks before his contemporaries even realized that some of the features they were seeing were shadows cast by mountains.

Thomas A. Dobbins

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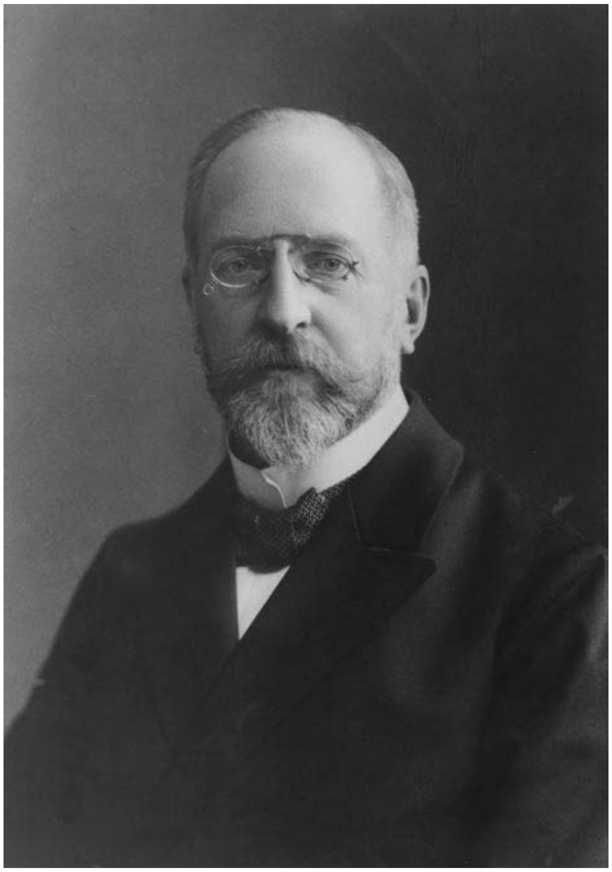
Hartmann, Johannes Franz

Born **Erfurt, (Thuringia, Germany), 11 January 1865**
Died **Göttingen, Germany, 13 September 1936**



German instrumentalist and spectroscopist Johannes Hartmann is remembered for the discovery of "stationary lines" in the spectrum of δ Orionis in 1904, which were soon after interpreted by **Vesto Slipher** as the discovery of diffuse interstellar material, and for devising the test for accuracy of figures of mirrors and lenses which bears his name. Hartmann was the son of Daniel Hartmann and Sophia (*née* Evers), and received his early education at Tübingen and Berlin before completing his doctoral thesis on the changing appearance of the Earth's shadow through lunar eclipses (Leipzig in 1891). He worked in Vienna with L. de Ball and back in Leipzig with H. Bruns (from whom he learned the mathematics he would later use in designing and testing astronomical instrumentation). Hartmann was appointed to a position at Potsdam in 1896 by **Hermann Vogel** and was promoted to observer (1898) and professor (1902). During those years, he measured large numbers of precise wavelengths of stellar features using a spectral comparator of his own design and also built a photometer for the observatory.

Potsdam installed an 80-cm refractor in the early 1900s, and Hartmann quickly discovered that the primary lens had not been ground accurately enough to make a useful photographic instrument. In 1904 he published the Hartmann test, which he had used to improve the objective lens. The photographic Hartmann test is an extension of the visual Foucault or knife-edge test, which makes use of photography rather than the observer's eye to record the pattern of the imperfect shape of the lens' surface and multiple light-admitting apertures rather than the single pinhole of the Foucault test.

Also in 1904, Hartmann reported that the spectrum of δ Orionis, observed through the period of the binary orbit, had lines of ionized calcium that did not shift back and forth in wavelength through the orbit period the way the lines from the photospheres of the two stars did. Vesto Slipher, **Walter Adams**, and others soon found more cases, and these "stationary lines" came to be attributed to interstellar gas, for which there had previously been no evidence.

In 1907, Hartmann married Angelika Scherr, and in 1909 they moved to Göttingen, where he became professor and director of the observatory. He was offered the directorship of the La Plata Observatory in Argentina in 1921; with German observatory facilities badly worn down by the stresses of World War I, he accepted the position. Once there, Hartmann found an 80-cm reflector in no better condition than the Potsdam refractor had been and modified his test method to apply to mirrors. Over the years, it has been used in the grinding and polishing of the mirrors for the 100-in. at Mount Wilson, the 120-in. at Lick Observatory, and the 200-in. on Palomar Mountain.

At La Plata, Hartmann participated in the campaign to measure the distance scale of the Solar System being coordinated by **Frank Dyson** by observing the exact position of (433) Eros during its 1930/1931 opposition throughout the night. In the process, he discovered that the apparent brightness of Eros varies periodically with time because it is not spherical, as has later turned out to be characteristic of all asteroids smaller than a critical size. Hartmann also discovered three additional minor planets, (965) Angelica, (1029) La Plata, and (1254) Erfordia, named in honor of his wife, his observatory, and his hometown. Returning to Göttingen at retirement age in 1934, Hartmann had hoped to engage in reduction of accumulated data, but succumbed to a lengthy illness, leaving behind his wife, two sons, and a daughter.

Christof A. Plicht

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Hartwig, Carl Ernst Albrecht

Born **Frankfurt am Main, (Germany), 14 January 1851**
Died **Bamberg, Bavaria, Germany, 3 May 1923**

Ernst Hartwig directed the Bamberg Observatory, independently discovered the supernova S Andromedae (SN 1885A), and was coauthor of a leading sourcebook on variable stars. Hartwig graduated from the Melanchthon Gymnasium in Nuremberg. Afterward, he studied astronomy, physics, and mathematics at four European universities. From 1874 to 1880, he was an assistant at the University of Strasbourg Observatory. For the next 2 years, Hartwig examined various observatories throughout continental Europe. In 1882, he led an expedition to Argentina to observe the transit of Venus across the Sun.

After 2 additional years spent at the University of Dorpat (in modern Estonia), Hartwig was appointed director of the observatory at Bamberg (1886). There, he had a large heliometer constructed to aid his research on the diameters of the planets and the Moon's physical libration. Hartwig became an enthusiastic observer of variable stars (chiefly long-period variables and U-Geminorum stars) and published ephemerides of their expected maxima and minima for the Astronomische Gesellschaft. In 1918, he coauthored, with **Gustav Müller**, a sourcebook on the history and literature of variable stars. His discovery of the "nova" S Andromedae touched off a long controversy over the distance and nature of this object and the Andromeda "Nebula."

K. Sakurai

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Hārūn al-Rashīd

Born **Rayy, (Iran), February 766 or March 763**
Died **Ṭūs, (Iran), 24 March 809**

Hārūn al-Rashīd, who reigned from 786 to 809, was the third son of Caliph al-Mahdī (died: 785) and the second son of a Yemeni slave girl called Khayzurān, freed and married by his father in 775/776. His education lay in the hands of the Barmakid Yaḥyā ibn Khālid (died: 805, Baghdad; killed on the caliph's order). In 782, Harun was appointed governor of the northern African, Egyptian, Syrian, Armenian, and Azerbaijanian territories of the ʿAbbāsid Empire, and declared second in succession. The powers behind this move were his mother and Yaḥyā ibn Khālid, who became the head of administration in these territories. In 786, in his early 20s, Hārūn became caliph after both his father and his brother died under suspicious circumstances. He chose as his Supreme Vizier Yaḥyā ibn Khālid who, together with his two sons Faḍl and Jaʿfar, ruled the empire for 17 years. Hārūn subsequently replaced them with groups entirely loyal to himself, mostly eunuchs and clients. Hārūn's reign was characterized by many serious uprisings against the caliphal power, although in *A Thousand and One Nights* it is portrayed as a period of glamour and splendor.

With regard to the arts and sciences, Hārūn continued the policies of his predecessors, although according to Arabic sources such as Ibn al-Nadīm's *Fihrist* these policies seem rather to have been instigated by his Barmakid vizier. During Hārūn's reign, a library was founded at the court with a director and several collaborators. Its scope and profile have been the subject of considerable debate in the literature. It apparently was closely related to the process of translating ancient texts into Arabic. D. Gutas has pointed out that the available evidence for this relationship privileges translations of Persian texts. He emphasizes that Ibn al-Nadīm's report about a translation of the *Almagest* linked to this library is the only explicit reference to a possible contribution of the library to translations of Greek texts. Ibn al-Nadīm claims that the director of the library, a certain Salm, and a second person known only as Abū Ḥassān, were called to court by the vizier in order to explain **Ptolemy**'s book. This event caused Salm and Abū Ḥassān to employ the best-known translators to translate Ptolemy's *Almagest*, check their translation, and make sure of its good literary style and accuracy (Ibn al-Nadīm, 2: 639). Unfortunately, we today know next to nothing about these translators or this translation; in any event this translation was most likely superseded by several others in the 9th century that may well have depended on it to some degree.

Sonja Brentjes

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Hāshimī: ʿAlī ibn Sulaymān al-Hāshimī

Flourished **890**

Hāshimī's only known astronomical work is his *Kitāb ʿIlal al-zījāt* (Book of the reasons behind astronomical tables); although it does not contain innovative ideas, it does provide a great deal of extremely useful information for the history of science and preserves materials from the Hellenistic world, India, and the Sasanians that would otherwise be lost. The unique 13th-century manuscript does not indicate the date of its original composition; however, it may date from the late 9th century since the treatise is mentioned by several authors from the 9th century, but none from the 10th.

The book is divided into sections on various aspects of astronomy. The first section is on *zīj*es (astronomical handbooks), and Hāshimī explains the meaning of a *zīj*, as well as provides a historical introduction with commentaries to various *zīj*es. These include **Ptolemy**'s *Almagest*, **Theon**'s *Canon*, the *Arjabhar*, the *Zīj al-Arkand*, the *Zīj al-jāmiʿ*, the *Zīj al-Hazūr*, the *Zīj al-Shāh* of Khusro Anūshirwān, the *Zīj al-Shāh* of Yazdigird III, **Fazārī**'s *Zīj al-Sindhind*, the *Zīj* of **Yaʿqūb ibn Ṭāriq**, the *Zīj al-Sindhind* of **Khwārizmī**, the *Mumtaḥan zīj* of **Yaḥyā ibn Abī al-Manṣūr**, the two *zīj*es of **Ḥabash**, and the (Thousands) *Zīj al-hazārāt* of **Abū Maʿshar**.

The *ʿIlal* also includes sections on chronologies and calendars; cycles and world-days; operations based on the cycles; equations, *kardaja*s, and sectors; the solar motion and related problems; lunar tables and equations; and miscellaneous subjects such as the lengths of night and day and equation of time, rising and setting amplitudes in the various climates, time of sunrise as affected by the Sun's declination, projection of the rays, and lunar and solar eclipses.

Hāshimī's *ʿIlal al-zījāt* provides us with a valuable indication of astronomy during this period as well as Hāshimī's understanding of certain astronomical texts. It is clear that this work is written at a time before the ascendancy of Greek astronomy in the Islamic world, when Indian and Sasanian astronomy were still on an equal footing with it.

Hāshimī also contributed to the development of mathematics, specifically calculation with irrational quantities.

Mònica Rius

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Hatanaka, Takeo

Born **Tanabe, Wakayama Prefecture, Japan, 1 January 1914**
Died **Tokyo, Japan, 10 November 1963**

Japanese theoretical astrophysicist and radio astronomer Takeo Hatanaka made his greatest mark through his ability to communicate astronomy, to bring people together, and to inspire them across disciplinary boundaries, particularly in the development of postwar Japanese radio astronomy and in the foundation of the Nobeyama Radio Observatory. He was adopted at age three by a family in Shingu, Wakayama,

and was educated there until he entered Tokyo Imperial University (today Tokyo University). He remained there for the rest of his life, receiving a first degree in 1937 and a Ph.D. in 1945, with a thesis (in English) "On the Theory of the Optical Interaction Among He II, O III, and N IV Atoms in a Planetary Nebula." Hatanaka taught at the university from 1937 onward and was promoted to full professor in 1953. Most of his career was spent at the National Astronomical Observatory, of which Nobeyama is now an important part.

Hatanaka became known as a communicator of science as a result of several radio and television broadcasts at the time of the 1957 launch of Sputnik. He wrote and edited for journals in both Japanese and English, served on committees for the United Nations and UNESCO, and was active in both national and international scientific organizations.

Inspired by **Yusuke Hagihara**, Hatanaka began work in 1948 in solar radio astronomy, a subject that had arisen out of wartime detections of solar radio bursts by radar installations in Germany, Britain, the United States, New Zealand, and Australia. He successfully detected bursts with a 6-m parabolic antenna in 1949.

In 1956, Mitsuo Taketani, Hatanaka, and Shinya Obi put forward a unified scenario for stellar populations and galactic evolution in which clouds of pure hydrogen and helium in the very early Universe made a first generation of stars (the remnants of which we see as population II today). Metals ejected by them mixed into the interstellar medium, which collapsed into a galactic disk from a spherical halo. Population I stars then began to form. One novel point was their suggestion that helium fusion occurred much more rapidly than had been calculated by Edwin E. Salpeter. This later proved to be incorrect, and the scenario was never fully fleshed out by its proponents. Many similar ideas are found in the galactic evolution model put forward in 1962 by Olin Eggen, Donald Lynden-Bell, and Allan R. Sandage, who most often receive credit for the general scheme. Slightly younger members of the Tokyo group became much better known internationally than Taketani, Hatanaka, and Obi, including Satio Hayakawa (cosmic rays), Chushiro Hayashi (pre-main-sequence evolution), M. Koshiba (nuclear astrophysics, cosmic rays, and neutrino astrophysics), Jun Jugaku (stellar spectroscopy), and Mitsuaki Fujimoto and Daichiro Sugimoto (stellar evolution).

Hatanaka died before his pioneering efforts bore full fruit, but an asteroid and a lunar crater are named for him, and he received posthumously one of Japan's highest honors, the Zuiho-sho (order of the sacred treasure, gold rays with neck ribbon). He and his wife Kinuko had one son and one daughter.

Steven L. Reshaw and *Saori Thara*

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Hay, William Thomson

Born **Stockton-on-Tees, (Cleveland), England, 6 December 1888**
Died **Chelsea, (London), England, 18 April 1949**

William Hay was an accomplished amateur astronomer who made one major discovery – the white spot on the planet Saturn – in 1933. To the public, however, he will be better remembered as Will Hay, the stage and screen comic actor.

Hay's father, William Robert Hay, an engineer from Aberdeen, Scotland, married Elizabeth Ebdon in 1884; their union produced six children. The Hay family moved to England and a few years after William, the future astronomer, was born at Stockton-on-Tees, the family relocated to Manchester. It was there, when he was 15, that Hay met Gladys Perkins; they were married in 1907. Hay became an engineer apprentice, but was never really comfortable in that role. He had a great aptitude for languages, and having taught himself French, German, and subsequently Italian, he became an interpreter for a printers' association in Manchester.

Meanwhile, Hay had taken part in charity entertainments as a juggler, and later as a comedian. After his marriage, he decided to abandon engineering in favor of the stage in 1909. Before long he had become a very successful professional music hall performer.

Hay's absorbing interest in astronomy also dated from this period, and it remained his main hobby for the rest of his life. Hay set up an observatory at Norbury, in Outer London, and equipped it with a 6-in. refracting telescope and a 12½-in. reflector. It was from here, on 3 August 1933, that he discovered the white spot on Saturn. As soon as Hay turned the 6-in. toward the planet he realized that there was unusual activity; he telephoned another well-known amateur, Dr. **William Steavenson**, who immediately confirmed it. The outbreak lasted for weeks, and was in fact the brightest spot seen on Saturn during the 20th century. It became visible with a small telescope, and at its greatest extent attained a length of 20,000 miles. The spot was used successfully for the determination of an accurate period of rotation for Saturn's equatorial zone.

Hay was a skilled observer; his principal interest was in measuring the positions of comets with an accurate crossbar micrometer he made for himself. His training as an engineer enabled him to construct excellent pieces of apparatus including several chronographs assembled from *Meccano* parts and scrap gramophone motors, and a functioning blink-comparator. In 1935, he published a small but very well written book, *Through My Telescope*. Hay served for several years on the Council of the British Astronomical Association. He was always careful to separate his astronomical interests from his stage career.

Medically unfit for military service during World War I (though he did volunteer), Hay developed his acting technique, and made his name largely as a comic schoolmaster. Following successful tours of Australia and South Africa (1923/1924) and America (1927), he found that he was in great demand.

In 1932, the same year in which Hay became a member of the British Astronomical Association and a fellow of the Royal Astronomical Society, he was regarded as one of the country's leading comedians, and in 1934 he made his first film, *Those Were the Days*. Others followed, some of which, notably *Oh, Mr. Porter!* and *Windbag the Sailor*, are recognized as classics of their kind. In his finest films Hay was joined by Moore Marriott and Graham Moffatt; the trio established themselves in the very forefront of the entertainment world.

Sadly, Hay's marriage broke up in 1934, though he and Gladys never divorced. His companion during his later years was Randi Kopstadt, a Norwegian actress. In addition to astronomy, Hay was intensely interested in sailing, and maintained a launch in the Oslo Fjord. He was also a private pilot and for several years in the mid-1930s owned his own airplane.

During World War II, Hay was active in entertaining the troops, and also gave many lectures on astronomy. Several of his wartime films were widely acclaimed, notably *The Goose Steps Out*, in which the Nazis were lampooned, and *The Black Sheep of Whitehall*. He suffered a stroke in 1946, and though he made a partial recovery he was forced to curtail his activities. Hay moved to Hendon, and transferred his observatory there; he kept up with his astronomical observations, and made occasional public appearances. Will Hay, who died peacefully, will be long remembered as a brilliant comic actor, but he also deserves to be remembered as a serious and energetic observational astronomer.

Patrick Moore

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Heckmann, Otto Hermann Leopold

Born **Opladen, (Nordrhein-Westfalen), Germany, 23 June 1901**

Died **Göttingen, Nordrhein-Westfalen (Germany), 13 May 1983**

German mathematician and astronomer Otto Heckmann was instrumental in founding the European Southern Observatory [ESO], of which he was the first director, and also wrote a text in theoretical cosmology that guided a generation of researchers in German-speaking countries.

After completing Gymnasium in the Rhineland, Heckmann entered the University of Bonn, completing a doctorate in 1925 with a thesis on the positions and proper motions of stars in the nearby cluster Praesepe, using plates taken at Bonn and under the directorship of **Karl Küstner**. That same year he married Johanna (*née*) Topfmeier who predeceased him by 2 years; they had three children.

For two additional years at Bonn, Heckmann worked on the theory of the dynamics of star clusters. (One of the important implications of his thesis observations and that theory is that clusters like Praesepe will dissipate after about 10^8 years.) Heckmann was then appointed to the faculty and observatory staff at Göttingen, from which he returned to Bonn as professor and director in 1942, holding that position until 1962 and remaining in Hamburg during his term (1962–1969) as director general of ESO. He retired to Reinbek, West Germany, and returned to Göttingen later in life.

During his terms in Göttingen and Hamburg, Heckmann came to fully appreciate the impossibility of pursuing certain kinds of astronomy under European skies. As a result, first, he focused observatory efforts on those things that could be done, most importantly the vital astrographic catalog AGK (with proper motions for 180,000 stars), coordinated from Bonn, but with contributions from a dozen other European observatories.

Second, Heckmann turned some of his own attention to theoretical problems, especially during the difficult years of World War II, publishing *Theorien der Kosmologie* in 1942. After the war he worked sporadically on general relativistic models of the Universe with strong anisotropies, which are sometimes collectively called Heckmann–Schucking–Behr cosmologies, partly with Engelburt Schucking and Alfred Behr.

Third, and perhaps most important, Heckmann joined with astronomical leaders in the Netherlands (**Jan Oort**), Sweden (**Bertil Lindblad**), and France (**André Danjon**, P. Bourgeois) to establish plans for a joint European observatory in the Southern Hemisphere, under the clear skies of Chile, and persuaded their governments to provide sufficient collective funding to establish a facility there and construct an initial set of telescopes, cameras, and spectrographs.

Heckmann himself had been partly responsible for the design of the Hamburg 1.2-m Schmidt, and was actively involved at all stages. The English Astronomer Royal of the time, **Harold Spencer Jones**, was also part of these discussions, but the United Kingdom decided to remain outside the ESO until more than 30 years later.

During the latter part of his ESO directorship, Heckmann was also president of the International Astronomical Union (1967–1970), and he had previously led both the astronomical and general science societies of Germany. He received honorary doctorates from Marseilles, La Plata, and Sussex and was a member or foreign associate of 11 academies of science. Heckmann received the Watson Medal of the US National Academy of Sciences, the Janssen Medal of the Société Astronomique de France, and the Bruce Medal of the Astronomical Society of the Pacific. Minor planet (1650) is named in his honor.

Paul A. Schons

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Hegel, Georg Wilhelm Friedrich

Born **Stuttgart, (Germany), 27 August 1770**
Died **Berlin, (Germany), 14 November 1831**

German philosopher Georg Hegel "proved" by use of logical reasoning that there can only be seven planets in the Solar System. His paper appeared just as **Giuseppe Piazzi** discovered the minor planet (1) Ceres, thereby bringing the number to at least eight.

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Heinrich of Hesse the Elder

➤ **Henry of Langenstein**

Heinrich von Langenstein

➤ **Henry of Langenstein**

Heis, Edward [Eduard, Edouard]

Born **Cologne, Nordrhein-Westfalen, (Germany), 18 February 1806**
Died **Münster, Nordrhein-Westfalen, Germany, 30 June 1877**

Edward Heis, whose birth certificate under the French occupation read Gustave Edouard Pierre Albert Heis, was an inexhaustible observer of meteors, variable stars, and their brightness, as well as of zodiacal light and the Milky Way. After graduating from the Königliche Karmeliten Gymnasium at Cologne in 1824, he began his studies in mathematics and philology at the University of Bonn. After receiving his teacher's training certificate in 1827, Heis taught mathematics and physics at his former school, now the Friedrich-Wilhelms Gymnasium, from 1830 until 1837, and then until 1852 at the Bürger-und Provinzial-Gewerbeschule (commercial high school) at Aachen.

In 1852, on the suggestion of **Alexander von Humboldt**, and with the support of Julius Plücker and **Friedrich Argelander**, Heis was appointed by King Frederick William IV to succeed Christoph Gudermann to the chair of mathematics (and astronomy) at the Königliche Theologische und Philosophische Akademie (University of Münster since 1902). Heis, who was rector of this academy in 1869, occupied his chair for 25 years before he died of apoplexy 3 months before his golden jubilee as professor. During the Vatican Council and the *Kulturkampf*, he stood faithfully by the church.

Heis wrote very popular mathematical textbooks, including the *Sammlung von Beispielen und Aufgaben aus der allgemeinen Arithmetik und Algebra*, which reached at least 107 editions in various languages, and the *Lehrbuch der Geometrie*, which also appeared in many editions. Heis was one of the founders of *Natur und Offenbarung* (1855), and editor of the scientific journal *Wochenschrift der Astronomie, Meteorologie und Geographie* (1857–1877).

Heis's early astronomical observations involved watching for shooting stars. The numerous meteors observed by Heis in 1838 radiated from a point near the star γ-Andromedae and were connected with Biela's comet(3D/1826 D1); they disappeared after 1852. Heis was the first observer to provide a precise hourly count for the August Perseids meteor shower, finding a maximum rate of 160 meteors per hour in 1839. He first observed the April Ursids from 16 to 30 April 1849, when he determined the radiant position as right ascension 150°, declination +61°. This work was continued by Giuseppe Zezioli (Bergamo) and **Giovanni Schiaparelli** (Milan) in 1868/1869. Heis's *Sternschnuppen-Beobachtungen* includes over 15,000 shooting stars that he and his students observed from 1838 to 1875.

Heis carried out his observations in Aachen from a lookout on top of the roof of the "Bürgerschule" (now torn down, located on the present Katschhof). Being endowed with exceptionally good eyesight, Heis generally devoted himself to the observation of all stars visible to the naked eye alone. In Münster, he had a 4-in. telescope located in a small observatory on the roof of the academy.

Argelander's *Aufforderung* (1844), in which he appealed to astronomers and amateurs to take up the study of variable stars, meteors, zodiacal light, and the Milky Way, also gave valuable suggestions for observing techniques, including a step method of estimating the brightness of a variable star among comparison stars. The result of Argelander's encouragement was dramatic; for example, from the 18 variable stars known in 1844, observers in Germany and around the world had catalogued more than 1,200 by 1911.

Heis was one of the first to take up the invitation. Heis's observations of zodiacal light extended over 29 years (1847–1875). He also turned his attention to the auroral light and to sunspots and published in 1867 a catalog of 84 meteoric radiant points. His famous star atlases (1872, 1878), the result of 27 years of labor by him and many collaborators throughout the world, include 12 charts and a catalog of 5,421 stars from the North Celestial Pole to 20° S of the Celestial Equator. They also include an elaborate delineation of the Milky Way as seen by the naked eye. Heis was the first to grade galactic luminosity into five magnitudes with a much-used 1–5 brightness scale, plotted on graph contours. His accompanying observations of variable stars from 1840 to 1870 appeared in print in 1903.

Heis's observations contributed to Argelander's famous *Bonner Durchmusterung*, a set of 37 large charts and a three-volume catalog, listing the positions of over 300,000 stars. Heis's additional observations, together with those of his collaborator **Johann Schmidt** (a former assistant of Argelander), culminated in the work *Atlas Stellarum Variabilium* of Heis's best student, **Johann Hagen,** of the Georgetown College Observatory.

Among Heis's many minor publications were treatises on the eclipses of the Peloponnesian War (1834), on Halley's comet (1P/Halley), on periodic shooting stars (1849), on the magnitude and number of stars visible to the naked eye (*De Magnitudine …*; 1852), on the star Mira (1859), and on the fable *E pur si muove* of **Galileo Galilei** (1874).

Heis received many professional honors. In 1852, he received an honorary doctorate from his *alma mater* at Bonn, presented by Argelander, professor of astronomy and director of the observatory there. Heis was decorated in 1870 with the order of the Red Eagle, nominated in 1874 as a foreign associate of the Royal Astronomical Society of London, and in 1877 as an honorary member of the Leopoldina Academy (Halle) and of the Société Scientifique de Bruxelles (Brussels). A lunar crater in the Mare Imbrium bears his name.

Paul L. Butzer

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Helicon of Cyzicus

Flourished **(Italy), 360 BCE**

Helicon of Cyzicus is said to have predicted an eclipse of the Sun, which took place as predicted.

Helicon was an astronomer and mathematician who studied with **Eudoxus**. He went to Syracuse, in Sicily, to teach the despot Dionysius II; while he was there, and during the third visit of **Plato** to Sicily, Helicon predicted an eclipse of the Sun. This took place as he had foretold. (It is identified with the annular eclipse of 12 May 361 BCE.) Dionysius was so impressed that he gave Helicon a talent of silver. Helicon is also said to have been able to solve the mathematical problem of the duplication of the cube, which perplexed many Greek mathematicians.

Katherine Bracher

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Heliodorus of Alexandria

Died **(Egypt), 509**

The son of Hermias, Heliodorus became known as a Neoplatonist. After studying with **Proclus** at Athens, he taught at Alexandria, where he made historically significant observations during the "silent centuries." Given the overwhelming success of **Ptolemy**'s *Almagest*, few observations survive from the late Hellenistic period. From the year 498 until his death, Heliodorus and **Ammonius**, his older brother, used an astrolabe to observe conjunctions of the planets and elongations of Venus and Mercury. Heliodorus made notes and corrections in his copy of the *Almagest*, which subsequently raised questions about the accuracy of Ptolemy's observations and methods. The works of Heliodorus are lost, but remaining fragments suggest he wrote several commentaries on astronomy and an introduction to the *Almagest*.

Robert Alan Hatch

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Hell, Maximilian

Höll, Miksa

Helmholtz, Hermann Ludwig Ferdinand von

Born **Postdam, (Germany), 31 August 1821**
Died **Berlin, Germany, 8 September 1894**

Hermann von Helmholtz, German mathematical physicist, is commemorated by the Helmholtz free energy (thermodynamics), Helmholtz coils (electromagnetism), and other eponyms. However, he is important within astronomy primarily for his association with the idea that the sun and stars derive their energy from gravitational contraction and with the time scale associated with that energy source, the Kelvin–Helmholtz time scale. (See **William Thompson**, Lord Kelvin.) The idea had its roots in the work by **Julius Mayer** (1841) and **John Waterston** (1843), in the papers rejected for publication by the Paris Academy and by the Royal Society of London, who suggested two ways of converting gravitational energy into heat – either the infall of meteoric material or contraction. Kelvin initially adopted the infall view and Helmholtz the contraction view. The discussions by Kelvin and Helmholtz were the ones that persuaded the scientific community of the importance of the ideas, partly because of their more careful calculations, partly because they tied the results more closely to the nebular hypothesis for the origin of stars with planetary systems, and partly because of their more-established positions in science. A gravitational origin for solar and stellar energy was generally accepted from about 1854 to the end of the 19th century. There is also a Kelvin-Helmholtz instability, which makes ripples at the interface between fluids flowing past each other and occurs in a variety of astrophysical contexts.

Helmholtz had broad-based interests and expertise, and made significant contributions to various disciplines. He was educated as a physician. He held the chair in physiology at the University of Königsberg through 1855, the chair in anatomy and physiology at the University of Bonn through 1858, and the chair in physiology at the University of Heidelberg through 1871. Then, following upon his growing reputation in physics and mathematics, he accepted the chair in physics at the University of Berlin.

In addition to his work in the sciences, Helmholtz was deeply interested in philosophy, music, and the arts. He criticized the theory of inherent knowledge (*a priori*) proposed by **Immanuel Kant** and stressed reliance upon empirical evidence. He is best known for his formulation of the law of the conservation of energy, *Über die Erhaltung der Kraft*. He also did fundamental work in mathematics, optics, electrodynamics, meteorology, thermodynamics, and physiology.

Helmholtz was elevated to the nobility in 1882 by the authority of Emperor William I. As a sign of the elevation, the title "von" was added to his name. In 1877, he was elected to the post of rector of the University of Berlin, a post that he held until 1878. In 1888, Helmholtz was appointed director of the newly formed Physico-Technical Institute of Berlin.

Helmholtz died before evidence began to accumulate that the sun and Earth were much older than the associated Kelvin–Helmholtz time of 30,000,000 years. Shortly after his death a statue was commissioned from the artist Ernst Herter. The statue, sculpted from Tyrolean marble, was placed at the entrance of the university and dedicated in 1899. The statue may be seen today in front of the Humboldt University of Berlin facing the street, Unter den Linden.

Paul A. Schons

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Hencke, Karl Ludwig

Born **Driesen (Drezdenko, Poland), 8 April 1793**
Died **Marienwerder (Kwidzyń, Poland), 21 September 1866**

Working with extremely simple means, the amateur astronomer Karl Hencke discovered two asteroids and five variable stars, and made notable contributions to the preparation of the Berlin Academic Star Charts. After attending the city school in his hometown, Hencke progressed through a career in the postal service that was interrupted in 1813 by his entry into a Prussian military corps during the war against Napoleon. In 1817, he became a postal secretary and managed the post office of his native city. At a comparatively young age of 45 years, he retired for health reasons in 1837. For 4 years thereafter, Hencke occupied an honorary civic post.

Hencke engaged in astronomical activity in addition to his professional duties and intensified his scientific pursuits after his retirement. In the skylight of his residence in Driesen, Hencke constructed an observatory. Around 1821, he bought an achromatic telescope from Utzschneider and **Joseph von Fraunhofer** in Munich and acquired an extensive library. The limited schooling given to him was supplemented by his unrelenting studies of specialist literature. As early as 1835, he was corresponding with professional astronomers. **Johann Encke** strongly supported the amateur in both word and deed, supplying him with, among other things, the latest scientific publications.

As Hencke became aware of the flaws in the existing star charts, he undertook to construct his own charts, a project that lasted several years. His breakthrough in astronomy came in 1845. First, he made an independent discovery of the great June comet C/1845 L1 from his rooftop observatory. Even more important was Hencke's discovery of asteroid (5) Astraea on 8 December 1845.

Hencke found Astraea to be a ninth-magnitude object during a systematic survey of the heavens in the vicinity of the minor planet (4) Vesta. Of course, Hencke initially entertained the possibility that he was viewing a variable star, but quickly rejected this idea because he had never detected a trace of any object in this section of the sky, which he had frequently observed over many years. Hencke's discovery was especially significant because it was the first discovery of an asteroid since the discovery of the first four asteroids between 1801 and 1807.

Hencke also discovered the next unknown minor planet (6) Hebe on 1 July 1847. However, he immediately assumed that this finding must be of a new asteroid, and informed both Encke and **Heinrich Schumacher** of this fact. Schumacher, for his part, informed the astronomical community in a circular printed in the *Astronomische Nachrichten* in which he stated that Hencke had announced another discovery and requested the submission of observations.

The discovery of Astraea was made with the help of the *Hora 4* chart from the Berlin Academic Star Charts (edited by **Karl Knorre** in Nikolajew, Russia), an international project initiated by **Friedrich Bessel** and led by Encke. Hencke participated in this project by editing the *Hora 20* chart in 1851. Encke deemed the *Hora 20* chart to be the one having the highest degree of difficulty (a rating given to only three of the 24 maps) on account of the star density in that specific region. Three other astronomers had already begun the work on *Hora 20* before Hencke, but they could not finish editing this particular chart.

As Hencke continued to revise and improve his own star charts, he discovered five variable stars: R Delphini (1851), R Camelopardi (1858), S Cephei (1858), S Coronae Borealis (1860), and U Herculis (1860).

The 349 sky charts made by Hencke between the North Celestial Pole and −28° declination were acquired by the Berlin Academy in 1868 at the urging of **Arthur von Auwers** and **Friedrich Argelander** and are now in the Archives of the Berlin-Brandenburg Academy of Science, Berlin. The refractor with which the discovery of Astraea was made is in the possession of the Archenhold Observatory in Berlin-Treptow.

The discovery of the two asteroids brought Hencke great renown and many honors. In 1847, through Argelander's intercession, the University of Bonn conferred the title of Doctor *honoris causa* upon Hencke. The Prussian state honored Hencke with a gold medallion for art and science, as well as the Order of Red Eagle, Class IV. The French Academy twice awarded Hencke the Lalande prize, and the Danish king decorated him with the medallion *Ingenio et arti*.

Jürgen Hamel

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Henderson, Thomas

Born **Dundee, Scotland, 28 December 1798**
Died **Edinburgh, Scotland, 23 November 1844**

Thomas Henderson, who served as Astronomer Royal for Scotland, was one of the first British astronomers to employ rigorous statistical methods in the analysis of observational data. He also performed the second known parallax measurement of a star (α Centauri).

Henderson was the youngest of five children born to a tradesman. He was married in 1836 and had one daughter. Henderson was educated at the Dundee Academy. He showed such proficiency in mathematics that the headmaster gave him private instruction on the subject. At age 15, Henderson began a 6-year apprenticeship to a lawyer in Dundee. He moved to Edinburgh in 1819, where he pursued a legal career while serving as clerk to Lord Eldin, Chief Justice of Scotland's Supreme Court, and later as private secretary to the Earl of Lauderdale and Lord Advocate Jeffrey. Simultaneously, Henderson took up astronomy as a hobby, acquiring practical skills at Calton Hill Observatory, operated by the private Astronomical Institution of Edinburgh.

Henderson burst into the astronomical spotlight during a creative spurt in the mid-1820s, when 12 of his papers were published in the *Quarterly Journal of Science* over a span of 3 years. Another paper, on the longitude difference between Greenwich and Paris, appeared in the *Philosophical Transactions* of the Royal Society in 1827. His new method of predicting the occurrences of lunar occultations was adopted for the 1827–1831 editions of the *Nautical Almanac*. During business trips to London, Henderson forged connections with noted British astronomers such as **John Herschel**, **George Airy**, and **James South**, who allowed him access to his own well-equipped observatory at Camden Hill.

In 1832, Henderson became director of the Royal Observatory at the Cape of Good Hope, following the premature death of its previous director, the Reverend **Fearon Fallows**. Henderson accepted the Cape position with great reluctance, having been turned down for both the chair of practical astronomy at Edinburgh University and the position of superintendent of the *Nautical Almanac*. In his private correspondence, Henderson referred to his remote posting as the "Dismal Swamp." In 1833, Henderson wrote a detailed memorandum to the Admiralty, in which he pointed out deficiencies of the Royal Observatory, arguing in the following manner:

> "[I]ts situation upon the verge of an extensive sandy desert [left it] exposed to the utmost violence of the gales which frequently blow, without the least protection from trees or other objects … the want of good water, and the state of the bulk of the population … will always prove considerable drawbacks from the comforts of persons sent from England to do the duties of the observatory … . "

His pleas for increased financial support went unheeded.

Saddled with a weak constitution and incipient heart disease, and disappointed by the observatory's mediocre equipment, Henderson remained in South Africa for only 1 year before returning to Scotland in May 1833. Nevertheless, his accomplishments at the Cape were impressive by any measure. He determined the precise latitude and longitude of the observatory; measured the parallaxes of the Moon and Mars, and from the latter inferred the Sun's distance; tracked the paths of comets 2P/Encke and 3D/Biela; recorded eclipses of Jupiter's satellites and occultations of stars by the Moon; timed a transit of Mercury across the face of the Sun; and dramatically accelerated the program to chart the Southern Hemisphere sky.

In 1834, after his return from the Cape, Henderson was appointed Astronomer Royal for Scotland and Regius Professor at the University of Edinburgh, a dual post that included the directorship of the Calton Hill Observatory. Over the next decade, in addition to reducing the Cape data, he secured some 60,000 positional measurements of Northern Hemisphere stars. Henderson is best known for obtaining the second reliable parallax measurement of a star, α Centauri. He recorded the relevant positional data while in residence at the Cape, but announced the resultant parallax, namely 1.16 ± 0.11″, before the Royal Astronomical Society only years later in January 1839, 2 months after **Friedrich Bessel** published his own parallax measurement of the star 61 Cygni. Shortly afterward, Henderson reported a preliminary parallax for the star Sirius. He died of heart disease.

Alan W. Hirshfeld

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Henricus Regius

➔ **Regius, Hendrick**

Henry, Joseph

Born **Albany, New York, USA, December 1797**
Died **Washington, District of Columbia, USA, 13 May 1878**

American scientist Joseph Henry used a thermoelectric pile to measure sunspot temperatures lower than the surrounding photosphere. His network of correspondents establish that aurorae are global (not local) phenomena.

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Henry of Langenstein

Born **near Langenstein, (Hessen, Germany), *circa* 1325**
Died **Vienna, (Austria), 11 Febrauary 1397**

Henry of Langenstein was an opposing voice contending with the prevalence of astrology in his day. The earliest reference to Henry dates from 1363, when he was a student at the University of Paris. After obtaining his degree he remained at the university as a regent master of arts, and he wrote most of his scientific works during this period. His works from the Paris period definitely reflect an influence of the university's grand master, **Nicolas Oresme**. Henry was forced to leave Paris in 1382 during the Great Schism when he refused to support the Antipope Clement VII. By 1383, Henry was invited to help in the revitalization of the University of Vienna, where he remained until his death.

Henry's initial scientific works were in the area of mathematical astronomy, and his earliest surviving astronomical work is *De reprobatione eccentricorum et epiciclorum* of 1364. This work reflects Henry's distaste for **Ptolemy**'s planetary system and his use of eccentrics and epicycles. Henry, like Ibn Rushd, preferred an astronomy that was true to Aristotelian mechanics, containing homocentric spheres. Henry's alternative demonstrated that he did not mind adopting Ptolemy's equant model to mimic nonuniform motion for the Sun and **Eudoxus**'s two-sphere model for the Moon.

Henry's mathematical work turned to astrological matters at the time of the appearance of the comet of 1368 (C/1368 E1). For reasons unknown to us, Charles V, King of France, asked Henry to compose a tract responding to the many astrological voices hailing the comet as a portent of the future. In his *Quæstio de cometa* of 1368, Henry rebuked the astrologers with the Aristotelian argument that comets are meteorological phenomena and are therefore unconnected to any constellation and have no astrological significance. He did, however, ascribe the comet's motion to the *primum mobile*, an odd connection to a body not part of the heavens. In the end, Henry invoked Oresme in his general criticism of astrologers, their fixation on superstition, and their unfortunate patronage by kings and magnates.

Henry's ire was piqued again in 1373 when many astrologers connected a conjunction of Saturn and Mars to a series of future wars and bad weather. In Henry's resulting work of the same year, *Tractatus contra astrologos conjunctionistas de eventibus futurorum*, he railed against the astrologers' inability to accurately forecast future events and pointed out other natural explanations for the few things they accurately predicted. Nevertheless, Henry did detail the factors that separated a proper astrologer from the quacks that he found to be an ill upon the land, including the ability to take into account all the factors that might affect the future. The Great Schism profoundly affected Henry, and after 1382 he spent more time on theological matters than on scientific issues, though he occasionally discussed philosophical concepts in his later works.

Ronald Brashear

Alternate names

Henry of Hesse the Elder
Heinrich von Langenstein

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Henry, Paul Pierre and Prosper-Mathieu

Henry, Paul Pierre

Born **Nancy, Meurthe-et-Moselle, (France), 21 August 1848**
Died **Montrouge near Paris, France, 4 January 1905**

Henry, Prosper-Mathieu

Born **Nancy, Meurthe-et-Moselle, France, 10 December 1849**
Died **Pralognan-la-Vanoise, Savoie, France, 25 July 1903**

As observational astronomers, and more particularly as creative optical workers, Paul and Prosper-Mathieu Henry were substantial contributors to French astronomical science in the late 19th century. They worked together throughout their life, united in such an unshakeable manner that it is impossible to separate the work done by one from that of the other. **Maurice Löwy**, director of the Paris Observatory, wrote in 1905 that "the two brothers succeeded in constituting together a scientific personality of a really high class." The perfection of the lenses and mirrors they polished, and the significant progress they made in astronomical photography, ensured them international fame.

These perfect autodidacts were born in a family too poor to allow them a formal education. After their elementary instruction the Henry brothers were completely self-trained. Their early mastery of optics came to the attention of **Urbain Le Verrier**, director of the Paris Observatory. At the age of 16, each brother was brought to Paris from Nancy and assigned to the weather observation and forecasting service that Le Verrier had only recently created at the Paris Observatory. Struck by their interest in astronomical work, Le Verrier offered them a shed in which they could establish a workshop and train themselves in optics. But it was in the small optical workshop equipped from their personal resources in their house in Montrouge that the Henry brothers preferred to conduct their research. There, they undertook the construction of a telescope (the mounting and the polishing of a 30-cm mirror). Also during their leisure, they began, in 1868, to draw a map of the stars in the ecliptic zone using a secondhand clock. Their intent was to complete a project initiated by **Jean Chacornac**.

In 1871, **Charles Delaunay**, director of the Paris Observatory assigned the Henry brothers to the observatory's equatorial telescope department. Their new duties included observation and sketching of the planets at each opposition. With the Henrys' discovery of a minor planet, (125) Liberatrix (so named probably as an allusion to the liberation of France at the time of the discovery), Delaunay formalized their project to map the stars in the ecliptic zone. The project was to survey the positions of all stars down to the 13th visual magnitude within a 5° wide sky band. Every year from 1871 to 1884, the Henrys published one or two ecliptic maps. During the period 1872–1882, they also discovered 14 new asteroids. It was impossible to identify which of the brothers had discovered each of the objects; therefore, the brothers decided to give the name of Paul to the odd-numbered discoveries and of Prosper to the even-numbered discoveries.

For the transit of Venus on 6 December 1882, the Henry brothers traveled to the summit of Pic du Midi. To complicate the matter beyond the obvious hazards of climbing the peak in the snow with the attendant risks of avalanches and subfreezing temperatures, and the problems of carrying heavy equipment for observing, there was, as yet, no formal observatory on this peak. Thus, one can imagine the disappointment the brothers must have felt when the sky clouded over on the day of the Venus transit.

By 1884, about one-fourth of the Henrys' ecliptic survey had been carried out – 36,000 stars were recorded – when they approached the crowded center of the Milky Way. There, the confusion due to the increasing number of stars made visual observations almost impossible. They thought of using photographic observation, recently improved by the invention of the dry photographic process using gelatinous silver bromide plates. Several observers (**Lewis Rutherfurd**, **Andrew Common**, and **David Gill**) had already obtained beautiful photographs of certain areas of the sky, but without reaching the expected degree of photographic resolution.

To implement a photographic program, the Henry brothers abandoned the ordinary long-focus refractors and devised a new shorter focal length instrument, better adapted to their aim. They polished a 16-cm doublet objective lens, achromatized for the blue wavelengths to which photographic plates are most sensitive. In another innovation, they coupled the photographic telescope to a visual guiding telescope to control precisely the tracking of the equatorial telescope during exposures lasting as long as 1 hour. Their results were so impressive that admiral **Ernest Mouchez**, the new director of the Paris Observatory, charged them with the construction of an equatorial astrograph suitable for preparation of a photographic map of the sky. Such a map was still only a dream as star mapping continued to be an arduous task at the telescope eyepiece.

The Henry brothers designed the optics for this instrument, while the mounting was designed by **Paul Gautier**. The photographic telescope featured a 34-cm, *f*/10 photographic refractor, coupled with a guiding telescope with an aperture of 25 cm and the same focal length as the camera. Completed in 1885, this astrograph quickly revealed its qualities; the Henry brothers obtained amazingly successful results. With a 3-hour exposure, they recorded up to 1,421 stars in the Pleiades cluster region, whereas 10 years earlier Rutherfurd, with a wet-plate process, had counted no more than 50 in the same area. At the same time, the Henry brothers' plate revealed the Maia Nebula around the star 20 Tauri in the Pleiades. That discovery was later confirmed visually with the Pulkovo Observatory 76-cm refractor.

The success was due to a rare perfection of the optical work realized by the Henry brothers. **David Gill**, director of the Cape of Good Hope Observatory, recognized their skill with great enthusiasm. Gill urged Mouchez to organize an international congress for a photographic survey of the sky. The *Congrés astrographique International pour le levé de la Carte du Ciel* met in Paris in 1887. The Henrys' astrograph was adopted as the standard instrument design for the cooperative international project. The Henrys actually built more than half of the 17 instruments required for the project. (See also **Howard Grubb**.)

The Henry name remains attached to the *Carte du Ciel* enterprise, but they went on to practice astronomy until their death. They never ceased manufacturing the fine optical parts for all the large French telescopes, such as those of Lyon (32-cm equatorial coudé refractor), Paris (60-cm equatorial coudé refractor), Nice (75-cm refractor), Toulouse (81-cm mirror), and Meudon (80-cm visual and 60-cm photographic refractors, and a 1-m mirror).

The Henry brothers' distinctive features were modesty, discretion, and abnegation. The unexpected death of Prosper, from a cerebral stroke during a journey in the French Alps, effectively stopped the work of his older brother as well. Paul was extremely affected and died at his home only 18 months after his brother, also carried off by a cerebral stroke.

The Henry brothers were awarded the Prix Lacaze of the Académie des sciences (1887), for all their works, and were elected associates of the Royal Astronomical Society (1899).

Raymonde Barthalot

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Henyey, Louis George

Born **McKees Rocks, Pennsylvania, USA, 3 February 1910**
Died **Berkeley, California, USA, 10 February 1970**

American theoretical astrophysicist Louis Henyey developed the modern numerical method of studying the theoretical evolution of stars in computer models. In Henyey's method, the computed structure from one computation is used as the initial guess for a somewhat later period, during which nuclear reactions slightly change the composition of the star. Henyey's iterative method quickly replaced an earlier one developed by **Martin Schwarzschild**.

Henyey was the son of Hungarian immigrants Albert and Mary Henyey. In 1938, he married the Budapest-born Elisabeth Rose Belak. They had three children, Elisabeth Maryrose, Thomas (a geologist), and Frank (a physicist).

Henyey received BS and MS degrees from the Case School of Applied Science in Cleveland in 1932 and 1933 and a Ph.D. in 1937 from the University of Chicago (Yerkes Observatory) with a thesis on radiative transfer in reflection nebulae in the interstellar medium. He and **Jesse Greenstein** developed in the next few years a formula used to describe how light is scattered in such gas clouds. Henyey remained at Yerkes Observatory as instructor and assistant professor until 1947. His career there was interrupted by a Guggenheim Fellowship year (1940/1941) with **Hans Bethe** at Columbia University. During World War II, Henyey worked at Yerkes Observatory with Greenstein in optical design.

In 1947, Henyey was appointed to an assistant professorship at the University of California, Berkeley, where he remained for the rest of his career (apart from a year at Princeton University, 1951/1952), becoming associate professor in 1948, full professor in 1954, and department chair and director of Leuschner Observatory (1959–1964). During the Princeton year, some of his work was classified, but he also interacted with John von Neumann and learned about computers and numerical methods for solving certain classes of (nonlinear) equations, of which those describing the interior structure of stars are a classic example.

Back at Berkeley, Henyey began building up a group of theoretical postdocs from physics and astronomy, including R. LeLevier, R. D. Levee, and Larry Wilets from Princeton University, and Karl-Heinz Bohm from Kiel University (now professor emeritus at the University of Washington). They worked largely with the UNIVAC computer at Livermore Radiation Laboratory, a defense facility, until Henyey was able to persuade the Berkeley administration that they needed their own computing facility; he became the first director of the Berkeley computing center in 1958. The group published the first version of Henyey's numerical method in 1959, which they had already applied to the evolution of stars before the onset of nuclear reactions. Their initial results showed, for example, that this early evolutionary phase must last about 30,000,000 years for a star about the mass of the Sun. An improved version of the code was published in 1964.

Henyey soon began adding graduate students to the group. Among those still active in the field are Peter Bodenheimer (University of California [UC]-Santa Cruz), William Hubbard (University of Arizona), William Mathews (UC-Santa Cruz), Roger Ulrich (UC-Los Angeles), and Silvia Torres-Peimbert (UNAM, Mexico City). Among the problems they addressed were the depletion of light elements (lithium, beryllium, and boron) in stars because these elements engage in nuclear reactions very readily and are quickly consumed; the effects of a heavy element abundance larger than that in the Sun (making stars red); and different methods of energy transport inside stars, including convection and semiconvection. Henyey was also a strong supporter of the establishment of the radio observatory at Hat Creek. He was still very active in astronomical research and science planning when he unexpectedly died of a cerebral hemorrhage.

Karl-Heinz Bohm

Acknowledgment

I am very grateful to Prof. Frank Henyey (Louis Henyey's son) for discussing with me important aspects of Louis Henyey's life.

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Heraclides of Heraclea

Born **Heraclea Pontica (Eregli, Turkey), *circa* 388 BCE**
Died **Heraclea Pontica (Eregli, Turkey), 315–310 BCE**

Greek philosopher Heraclides was the son of Euthyphron, who was a wealthy man of high status at Heraclea Pontica. (One of his ancestors was an original founder of this Greek colony on the south coast of the Black Sea.) Heraclides attended the academy in Athens and was left in charge of it during **Plato**'s third visit to Sicily in 360 BCE. Although he was a pupil of Plato, Heraclides studied with **Aristotle** and with Speusippus (Plato's nephew and successor as head of the academy). When Speusippus died in 339 BCE, Heraclides tried to become the next leader of the academy, but Xenocrates, another of Plato's disciples, triumphed by just a few votes. In the same way, Heraclides kept contact with some Pythagorean philosophers and was strongly influenced by their philosophy.

Following the greatest part of ancient and modern sources, Heraclides was the first to clearly explain that the apparent rotation of the heavens is brought about by the rotation of the Earth on its axis rather than by the global movement of stars around the Earth. He proposed that the seeming westward movement of the heavenly bodies is due to the eastward rotation of the Earth on its axis, although he kept a geocentric universe.

Nevertheless, a few ancient authors, like **Cicero**, wrote that two obscure Pythagoreans, **Hicetus** of Syracuse and **Ecphantus** of Syracuse (the second being probably the disciple of the first one and who lived at the end of 5th century BCE), proposed the same theory, the axial rotation of the Earth, before Heraclides. But so little is known about them that it was said that they could be two fictitious characters of one of his lost dialogs.

According to a commentary on Plato's *Timaeus*, written by Calcidius in the 5th century, Heraclides would have suggested that the two planets Mercury and Venus orbited the Sun, which itself was moving around the Earth. This peculiar view of the Universe, whose name is the geo-heliocentric system, found favor with three late Roman Empire writers (Calcidius, **Macrobius**, and **Martianus Capella**) from the 5th century. It also found favor with some scholars during the high Middle Ages (especially **Alcuin**, Rabanus Maurus, and John Scot Erigena who proposed that Mars and Jupiter also orbited the Sun). Far later, during the 16th century and with the fall of the Ptolemaic system, **Paul Wittich** and **Tycho Brahe** proposed the same geo-heliocentric system where the five planets, including Saturn, orbited the Sun.

From the beginning of the 19th century until fairly recently, it was believed, especially by T. H. Martin and **Giovanni Schiaparelli**, that Heraclides really suggested that Mercury and Venus orbited the Sun. The last one went further to claim that Heraclides must have proposed the theory that the Sun revolves round the Earth (but the planets revolve round the Sun). This theory was never, as far as we now know, put forward by a Greek astronomer.

Moreover, several modern scholars are now thinking that Heraclides did not propose any geo-heliocentric theory. The misunderstanding came from a bad reading of Calcidius's commentary, which received a more accurate translation by **Otto Neugebauer**. D. C. Lindberg gave a wealth of recent references that clearly indicate that Heraclides's theories never espoused heliocentrism, which was rejected at its time because it was believed that the rotation of the Earth would cause falling bodies to be deflected westward.

Heraclides had been the author of numerous Plato-like dialogs over many subjects, including astronomy (On the celestial bodies). Unfortunately, all of them are lost, and we only have the titles (especially by Diogenes Laertius) and some poor extracts.

Christian Nitschelm

Alternate names

Heraclides of Pontus
Heraclides Ponticus

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Heraclides of Pontus

➔ **Heraclides of Heraclea**

Heraclides Ponticus

➔ **Heraclides of Heraclea**

Heraclitus of Ephesus

Born **Ephesus (near Selçuk, Turkey), *circa* 540 BCE**
Died ***circa* 480 BCE**

Heraclitus is mostly known for his notion that "one can and cannot step in the same river twice," thereby raising problems of identity, persistence, and change that would become hallmarks of the western philosophical tradition. However, he also had a passing interest in cosmology, though it seems that his observations were made to suit his philosophical interests and were mere modifications of earlier mythological views, rather than being based on sound empirical study.

Heraclitus was the eldest son of Bloson and a member of a leading aristocratic family of Ephesus. He was a loner with a general distaste for mobs. Consequently, he had no pupils, though a small book that he wrote had a rich tradition of its own and attracted many followers; the Stoics recognized it as the source of their doctrines. All that survives of this book is a series of quotations that scholars have been able to extract from other sources and that reveal an enigmatic and oracular style, perhaps adopted by Heraclitus to protect its true contents from commoners. Owing to its obscurity, the book engendered many anecdotes about its author, most of them intending to malign him, and so it is difficult to know much about his life and character that is reliable. It is equally difficult to discern the details of his true thought.

According to Heraclitus, the Sun was an inverted bowl that floated across the sky collecting vapors (or exhalations) that arose from land and sea. The vapors from the land were warm and dry, igniting in the bowl and causing it to rise high in the sky. But the vapors from the sea were cold and moist, thereby extinguishing the fire in the bowl, causing it to set over the sea in the west. This process would be repeated again the next day. Like the Sun, the Moon and stars were also bowls, the stars glowing lighter because they were further away from the observer and the Moon glowing lighter because it collected impure vapors. Eclipses of the Sun and Moon, and the phases of the Moon, were explained by the notion that the pertinent bowls would turn away from the Earth from time to time. Heraclitus gave no account of the composition of the bowls themselves, though concerning the bowl of the Sun he reputedly said that "its breadth is the length of a human foot" and that "it is of the size that it appears to be."

Anthony F. Beavers

Alternate names

Heraclitus the Riddler
Heraclitus the Obscure

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Heraclitus the Obscure

➲ **Heraclitus of Ephesus**

Heraclitus the Riddler

➲ **Heraclitus of Ephesus**

Herget, Paul

Born **Cincinnati, Ohio, USA, 30 January, 1908**
Died **Cincinnati, Ohio, USA, 27 August, 1981**

Paul Herget, director of the Cincinnati Observatory and first director of the International Astronomical Union's Minor Planet Center [MPC], pioneered the use of punched-card machines for orbital calculations.

Herget received his A.B. (1931), M.A. (1933), and Ph.D. (1935) degrees from the University of Cincinnati, where he then spent most of his career. During World War II he was on the staff of the Nautical Almanac Office, where, with **Wallace Eckert**, he used punched-card equipment to prepare the *Air Almanac*.

Returning to Cincinnati in 1946, Herget became director of the Cincinnati Observatory. In 1947, the International Astronomical Union's MPC, formerly in Berlin, was moved to Cincinnati. It remained there under Herget's direction until his retirement in 1978, when it was moved to the Harvard-Smithsonian Center for Astrophysics. As director of the MPC, Herget was responsible for publishing the *Minor Planet Circulars*, collecting observations of asteroids, and calculating orbits and positions; he also had considerable success in the recovery of lost asteroids.

Herget used punched-card machines for these computations. The approximately 4,390 *Minor Planet Circulars* published during his tenure were printed directly by a computer so as to minimize the introduction of errors.

Herget also calculated the orbits of comets and planetary satellites, especially those of Jupiter, and the Jovian Trojan asteroids. He worked closely with Eugene Rabe of the University of Cincinnati, who was also instrumental in founding the MPC, and provided a plate reduction service for astronomers/institutions that could not otherwise reduce their astrometric data.

In the 1950s, Herget served as a consultant to several organizations working on computing satellite orbits. He also set up computer programs for International Business Machines to calculate the orbits for launches of the Project Mercury spacecraft. Herget's work in orbit calculation and celestial mechanics was recognized by his election in 1962 to the National Academy of Sciences and by his receipt of the Dirk Brouwer Award of the American Astronomical Society's Dynamical Astronomy Division in 1980. Both the city and the University of Cincinnati also honored him.

Herget married Harriet Louise Smith in 1935. After her death in 1972, he married Anne Lorbach.

Katherine Bracher

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Herman, Robert

Born **New York City, USA, 29 August 1914**
Died **Austin, Texas, USA, 13 February 1997**

Robert Herman, American physicist, engineer, and cosmologist, is best known for his work with **George Gamow** and **Ralph Alpher** on nuclear reactions and radiation in the early Universe. Herman received a BS in physics from the City College of New York in 1935 and a Ph.D. in physics from Princeton University in 1940, for work on molecular structure and infrared spectroscopy. Both as a student and later, he switched freely between theoretical and applied physics and published in a wide range of fields.

After receiving his Ph.D., Herman spent a year at the Moore School of Electrical Engineering, University of Pennsylvania, where he worked on early digital computers. When the United States entered World War II, he joined a section of the Office of Scientific Research and Development, being established at the Department of Terrestrial Magnetism, Carnegie Institution of Washington. In 1942, that section became the Applied Physics Laboratory [APL] of Johns Hopkins University, where Herman remained until 1956. During the war, he worked primarily on operations analysis of the efficacy of variable-time fuses (proximity fuses) for rotating projectiles. After the war, he became head of a molecular spectroscopy group largely concerned with combustion reactants, served for several years as assistant to the director of APL, and did research on color centers in alkali halide crystals.

Beginning in 1947, Herman, Alpher, and Gamow became some of the very first people to take seriously the question of what the early Universe was like and what relics of it we might find today. Although the initial conditions they chose (pure neutron matter, rather than thermal equilibrium) were wrong, their concept of nuclear physics was right. They were able to show that a universe that had expanded out of hot, dense conditions (what we now call a "Big Bang") should consist of about 25% helium and 75% hydrogen, as the Universe indeed does. Alpher and Herman also concluded that the hot state should still be distantly visible in the form of radiation that was once γ rays, but might now have a temperature close to 5 K. That radiation was discovered, accidentally by Arno Penzias and Robert Wilson, in 1965; the temperature is about 2.73 K.

In 1955, Herman spent a year as visiting professor at the University of Maryland. In 1956, he moved to the Research Laboratory of General Motors Corporation in Warren, Michigan, where he headed both the theoretical physics and the traffic science departments. Among his contributions there were work with Robert Hofstadter of Stanford University using scattering of high-energy electrons to trace out the structure of atomic nuclei (for which Hofstadter shared the 1961 Nobel Prize in Physics) and the development of vehicular transportation science as an operations research discipline. Herman was elected to the National Academy of Engineering in 1978 for his work in transportation science. (He also accumulated a superb collection of cartoons concerning traffic jams and other ills to which the American transport system is heir.) Some of this work was done in collaboration with people like Elliott Montroll and Ilya Prigogine who were prize-winning physicists in related disciplines like thermodynamics.

Herman retired from General Motors in 1979 and joined the faculty of the University of Texas, where he became the L. P. Gilvin Centennial Professor. Among his nonphysics interests were the theory of the English flute, measurement of pupillary diameters, and wood sculpture. At the time of his death, work in progress included papers on traffic problems and pavement materials, and a book on cosmology with Alpher.

Douglas Scott

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Hermann the Dalmatian

Flourished **(Spain), 1143**

Hermann translated part of **Ptolemy**'s *The Planisphere* from Arabic to Latin, and thus reintroduced the West to planispheric projection (*e. g.*, the astrolabe).

Selected Reference

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Hermann the Lame

Born **Altshausen, (Baden-Württemberg, Germany), 18 July 1013**
Died **Reichenau Monastery, Reichenau, (Baden-Wűrttemberg, Germany), 24 September 1054**

Hermann was one of the most important scholars of the 11th century. He was the son of the Swabian count Wolferat. At the age of seven, he entered the monastery, and was ordained as a monk in 1043. Lame from youth (hence his name), he was unable to walk or move by himself, and it was only with difficulty that he was able to speak. Hermann is one of the great examples of how a healthy mind can exist in an ill body.

Hermann's fame reached well beyond the monastery's walls; his students often came from far away to learn from his wisdom, and despite his disabilities, he was well respected. Hermann also spent his time writing about music, computistics, mathematics, history, and astronomy.

With his writings about the astrolabe, Hermann is "one of the key figures in the transmission of Arabic astronomical techniques and instruments to the Latin West before the period of translation" (Kren, p. 301). His student Berthold von Reichenau also reported that Hermann was fluent in Arabic; this fact is much disputed, however. Hermann is sure to have received scripts that had already been translated from Arabic to Latin in the 10th century in the monastery of Santa Maria di Ripoll in the north of the Iberian peninsula. His work proves that in his times, knowledge of the Islamic sciences had penetrated to the region of southern Germany.

In Hermann's two writings *De Mensura Astrolabii* and *De Utilitatibus Astrolabii* – of the latter only the second part is attributed to Hermann – he introduced into western science three instruments for heavenly observations: the astrolabe, the cylinder sundial, and the quadrant.

It is further known that Hermann commissioned an astrolabe for the monastery of Reichenau (latitude of 48°), and he calculated a catalog of the 26 astrolabe stars. In *De Mensura* he taught the depiction of the circles, and construction of the rete and the shadow square. His text contains many Latin translations of Arabic terms. Hermann provided a description of the cylinder sundial based on an Islamic model that was adapted to a well-liked type of the travel sundial (*horologium viatorum*), which indicated the irregular lengths of the temporal hours. For the quadrant, Hermann again had knowledge of the Islamic models. His instrument was capable of measuring the Sun's altitude by aiming at the Sun and then reading the altitude on a scale from 0° to 90° with a plumb line. Time could also be read by moving a marker on the plumb line according to the respective month, and then reading the marker's shadow on a scale that had the hour lines etched into the surface.

Hermann's depiction and mathematical development of the Earth's diameter measurement by **Eratosthenes** (with $\pi = 22/7$) in the second part of the book *De Utilitatibus* is of utmost importance, as is the letter by Meinzo of Constance sent to Hermann before 7 June 1048, which indicates that the Earth was known as a sphere in medieval times.

Hermann's *Chronicle of the World*, beginning with the birth of Christ, demonstrates not only great diligence but also his accuracy and careful evaluation of original sources. With regard to historical events in his lifetime, this book is a reference of the first rank for later works.

Jürgen Hamel
Translated by: *Balthasar Indermühle*

Alternate names

Reichenau, Hermann von
Hermannus Contractus

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Hermannus Contractus

➜ **Hermann the Lame**

Herrick, Edward

Born **1811**
Died **1861**

Edward Herrick owned a bookshop in New Haven, Connecticut, USA. In 1837, Herrick's was one of three independent observational discoveries of the annual Perseid meteor shower recorded in modern times. (The others were made by **Lambert Quetelet** and **John Locke**.) Herrick also proposed a radiant for the Lyrid meteor shower based on historical records.

Selected Reference

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Herschel, Alexander Stewart

Born **Feldhausen, (South Africa), 5 February 1836**
Died **Slough, Berkshire, England, 18 June 1907**

Alexander Herschel developed early methodologies for studying meteor spectra visually, and he correctly interpreted the physical significance of the resulting data. He also discovered an important harmonic law of molecular spectroscopy.

Herschel was the second son of 12 children born to **John Herschel** and Margaret (*née* Stewart) Herschel. Alexander's earliest education was under private tutelage, but at 15 years of age, in 1851, he was sent to Clapham Grammar School in London, then under the headmastership of the Reverend **Charles Pritchard** (who later became Savilian Professor of Astronomy at Oxford). Clapham Grammar School was renowned for its science-teaching curriculum; Herschel excelled in the mathematical and physical sciences during his time at the school. In 1855, Herschel proceeded to Trinity College, Cambridge, where he graduated with a BA as 20th wrangler in 1859; he was further awarded an MA by Trinity College in 1877.

Between 1861 and 1865, Herschel studied meteorology at the Royal School of Mines in London. Interest in meteors was high at that time, and Herschel began working on the heights of meteors, publishing at least one paper in 1862, and writing letters to **Lambert Quetelet** and others on the subject. Interest in the nature and composition of meteoroids was further enhanced in 1861 with the publication of **Daniel Kirkwood's** speculative work suggesting that meteors were cometary debris. During his time in London, Herschel initiated the study of meteor spectroscopy. To this end, he had specifically designed and built a slitless, binocular-style spectroscope that had a wide field of view (an essential attribute of any meteor-observing instrument). Herschel began to use his meteor spectroscope as early as 1864, but it was with the publication of his studies of Perseid meteors in 1866 that a strong case could be made for the identification of sodium in meteor trails. Herschel correctly identified the strong yellow line that he saw in many Perseid spectra as being due to the sodium doublet (the d-line of Fraunhofer). This feature was also observed by Herschel (and others using similar spectroscopes especially built for the British Association) during the 1866 Leonid meteor shower. Herschel also recorded and identified the green line due to magnesium in meteor spectra. The spectroscopic studies initiated by Herschel revealed, for the first time, that meteors produce their light by an emission process, and they also provided the first clues as to the chemical make-up of meteoroids.

In 1866, Herschel was appointed as lecturer on natural philosophy and professor of mechanical and experimental physics at Anderson's College in Glasgow (now Strathclyde University), Scotland. As an accomplished spectroscopist, it was natural that he would meet and become acquainted with **Charles Smyth**, Astronomer Royal of Scotland, and encourage the latter to take up laboratory spectroscopy. Herschel was a frequent visitor in the Smyth home, even after leaving Glasgow to return to England.

In addition to his spectroscopic work, Herschel gained great renown as a meteor observer and for his skill in determining accurate positions of meteor-shower radiant points. Indeed, it was by using Herschel's radiant point for the 1866 Leonid meteors that **Giovanni Schiaparelli** deduced an orbital identity between the Leonid meteoroids and comet 55P/Tempel–Tuttle. Herschel's reputation was further advanced when he drew attention to and predicted a strong return of the Andromedid (also Bielid) meteors in 1872. The Andromedid meteoroids had earlier been associated with comet 3D/Biela, whose nucleus had split into two fragments *circa* 1844 and which had been lost since 1852. A veritable storm of Andromedid meteors was observed in November 1872; this event helped establish the close association between comets and meteors.

Herschel resigned his professorship at Glasgow in 1871 to accept an appointment at the University of Durham as professor of physics and experimental philosophy. The facilities when he arrived were quite inadequate for teaching experimental physics. Many observers have commented on Herschel's effectiveness in developing the necessary laboratory resources on a limited budget, in part by investing his own funds for equipment. His work on meteors continued unabated. In an important paper published in the *Monthly Notices of the Royal Astronomical Society* in 1878, Herschel presented a list of 71 theoretical radiant points for various comets, and drew attention to the possibility of an association between the η Aquarid meteor shower and comet 1P/Halley. Between 1874 and 1881, Herschel, working principally with Robert P. Greg, collated vast amounts of observational data relating to meteor radiants and atmospheric paths, and compiled annual reports for the Luminous Meteor Committee of the British Association for the Advancement of Science. He also prepared extensive annual reports, published each February from 1872 to 1880, on meteoritic astronomy for the Royal Astronomical Society.

As Smyth improved the resolution of his spectroscopes, Herschel became interested in the problem of mathematically identifying lines that formed a series within a complicated spectrum. Smyth's penchant for representing spectra in wave numbers, $1/\lambda$ (albeit in British inches), simplified Herschel's problem of recognizing patterns in the complex spectra. In 1883, using a very high dispersion spectroscope, Smyth resolved the green line in the spectrum of CO into a bewildering array of primary single lines and newly resolved doublets. On examining the resolved green line spectrum, Herschel devised a simplified ruler for the primary lines, and then sliding that marked ruler along the wave number scale found lines that matched this spacing identically among the newly resolved secondary lines. He thereby identified the lines that belonged in this homologous series and was able to quantify the geometrical progression involved. Herschel's relationship precisely matched the one independently established by **Henry Deslandres** 3 years later as the first law of band spectra.

Herschel resigned from his professorship at Durham in 1886 and shortly thereafter took up lodgings at his grandfather's (Sir **William Herschel**) old home, Observatory House, in Slough. Herschel was elected a fellow of the Royal Astronomical Society in 1867, and in that same year he also became a member of the Physical Society of London. In 1884, Herschel was elected a fellow of the Royal Society. Between 1885 and 1887, Herschel acted as president to the Newcastle upon Tyne and Northern Counties Photographic Association, and in 1892 he became a member of the Society of Arts. The University of Durham bestowed an honorary Doctorate of Civil Law on Herschel in 1886, and in 1888 the Physics Laboratories at the newly located College of Physical Science of the University of Durham (now forming part of the University of Newcastle upon Tyne) were also named in his honor. Herschel never married and had no children.

Martin Beech

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Turner, H. H. (1908). "Alexander Stewart Herschel." *Monthly Notices of the Royal Astronomical Society* 68: 231–233.

Herschel, Caroline Lucretia

Born **Hanover, (Germany), 16 March 1750**
Died **Hanover, (Germany), 9 January 1848**

Perhaps the most famous woman in the history of astronomy, Caroline Herschel discovered eight comets and was the first professional female astronomer, yet she seems fated to live in the shadow of her brother, **William Herschel**. Caroline was the eighth of 10 children (only six of whom survived) born to Isaac Herschel and Anna Ilse Moritzen, in Hanover, Germany. Isaac Herschel, a bandmaster in the Hanoverian Guard, raised his sons in a musical-military tradition. Music defined the Herschel household, though natural philosophy was frequently the topic of dinnertime conversation. In neither of these activities was Caroline an active participant, though much later she became a somewhat accomplished singer under the sporadic tutelage of William. Caroline was extremely devoted to her father and brothers, but she was especially fond of William, and was heartbroken by his immigration to England when she was seven.

For 9 years, William worked as an itinerant musician until he obtained a position in 1766 as the organist in the Octagon Chapel in the resort town of Bath. To Caroline's great relief, in 1772, William visited Hanover and brought her back with him to England. Caroline's fate – or at least her shortlived musical career and subsequent astronomical accomplishments – paralleled that of William.

Even while he continued to write music and to give music lessons to students and to his sister, who joined him not only in copying music but also in giving public performances, William's passion turned to astronomy. William bought popular books on astronomy and optics, leased some small telescopes, bought equipment for making his own reflectors, and began observing the skies by early 1774. Caroline found herself working as William's assistant, helped somewhat by their brother Alexander. Under William's tutelage, she learned to grind and polish mirrors and to construct tubes. Unbeknownst to them, they were making the most powerful telescopes then available anywhere in the world, including their first 20-ft. focal-length reflector built in 1776. William also taught Caroline some mathematics necessary for astronomy. By helping in so many aspects of astronomy, Caroline became by default an expert astronomer, though in her humility (and likely some bitterness) she considered herself merely an astronomer's helper.

By 1779, William regularly and methodically observed the entire night sky, investigating many objects already known and discovering new ones. Soon after William's discovery of the planet Uranus on 13 March 1781, he and Caroline moved to Datchet, near Windsor Castle. As William left his musical career behind and focused on astronomy full-time, Caroline had little choice but to do the same, aiding William as he built increasingly larger telescopes, culminating with their massive 40-ft. reflector, finished in 1788. William observed atop the telescopes, calling down to Caroline what he was seeing and where; she recorded those observations, copied them the next day, and later reduced them for assembling a catalog. Although it was not her ideal profession, so adept was Caroline at the mathematics necessary for accurately recording and processing William's observations that she was soon able to undertake her own observational program.

At William's command, Caroline began her own observations sometime around 1780, using a variety of different telescopes, including specially designed small Newtonian "comet sweepers." In the next few years, she found new nebulae, star clusters, double stars, and, most notably, comets. She discovered her first comet (C/1786 P1) on 1 August 1786, and astronomers throughout Europe soon confirmed it. The following year, King George III awarded Caroline a pension of her own, giving her £50 annually as her brother's official assistant, making her the first woman paid as a professional astronomer. She discovered five more comets that now carry her name: 35P/1788 Y1, C/1790 A1, C/1790 H1, C/1791 X1, and C/1797 P1. She also independently discovered comets C/1793 S2 (Messier) and 2P/1795 V1.

Although it was not known at the time, Herschel rediscovered (in 1795) the comet that was originally seen in 1786 by **Pierre Méchain**. This same comet was later observed in 1818 by **Jean-Louis Pons**, but it was **Johann Encke** who first demonstrated (from the orbital elements) that all three comets were one and the same object, having a very short orbital period of around 3.3 years.

Caroline also took the information from the star catalog of the first Astronomer Royal, **John Flamsteed**, and compiled lists of stars in zones of declination 5° wide to assist William's sweeps of the sky as he searched for double stars and nebulae. In 1798, she published a revised version of Flamsteed's star catalog, contributing an additional 561 stars Flamsteed had not included and correcting many errors.

Caroline thus not only participated in her brother's astronomical discoveries, but also was a solid astronomer in her own right. After William's marriage in May 1788, however, Caroline felt displaced. Her own astronomical pursuits reflected her general desire to be of assistance to William; her aid on both fronts was now needed less and less, a situation furthered by her moving out of William's home. Even so, Caroline soon had a new member of the Herschel family on whom she could dote: William's son, **John Herschel**, born in 1792, who became one of the most celebrated 19th-century men of science. As a boy, John received considerable attention from Caroline, and his close relationship with his aunt lasted until her death.

After William's death in 1822, Caroline returned to Hanover. Over the next few years, she finished the catalog of the 2,500 nebulae and star clusters William had observed. For this work she was awarded the 1828 Gold Medal of the Astronomical Society of London (later the Royal Astronomical Society). Caroline and John remained in regular contact via an extensive correspondence, with John also visiting her on occasion. During his astronomical expedition to South Africa, John and his wife, Margaret, wrote to Caroline to keep her informed of John's discoveries. When Halley's comet returned during this period, John wrote excited letters to Caroline so that she, herself a great discoverer of comets, could be informed of his observations of it.

Caroline remained in Hanover until her death. Near the end of 1847, she received a final, important gift: a specially bound copy of John's recently published astronomical observations from Cape Town. These observations represented the completion of a survey of the entire night sky, undertaken by William, Caroline, and John in the Northern Hemisphere, and completed by John in the Southern Hemisphere. The publication brought a closure to her own years as an astronomer. A few months later, Caroline died peacefully in her sleep.

Caroline's contributions to astronomy are inevitably linked to serving as her brother's assistant and *amanuensis*. Indeed, she wrote drafts of every one of his many papers published in the *Philosophical Transactions*. Her comet discoveries and revision of Flamsteed's catalog earned her considerable renown in her own right among astronomers. Even there, however, she could not escape from William's shadow: Although **Joseph de Lalande** wished to nominate her for a prize awarded by the Assemblée Nationale in 1792, it went instead to William.

Steven Ruskin

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Herschel, John (Jr.)

Born **Cape Town, (South Africa), 1837**
Died **31 May 1921**

John Herschel, son of Sir **John Herschel** and grandson of **William Herschel**, was a military officer. He was also a third-generation astronomer. Herschel (in India) was among those who first observed the hydrogen spectrum in a solar prominence, during the total eclipse of the Sun on 18 August 1868.

Patrick Poitevin

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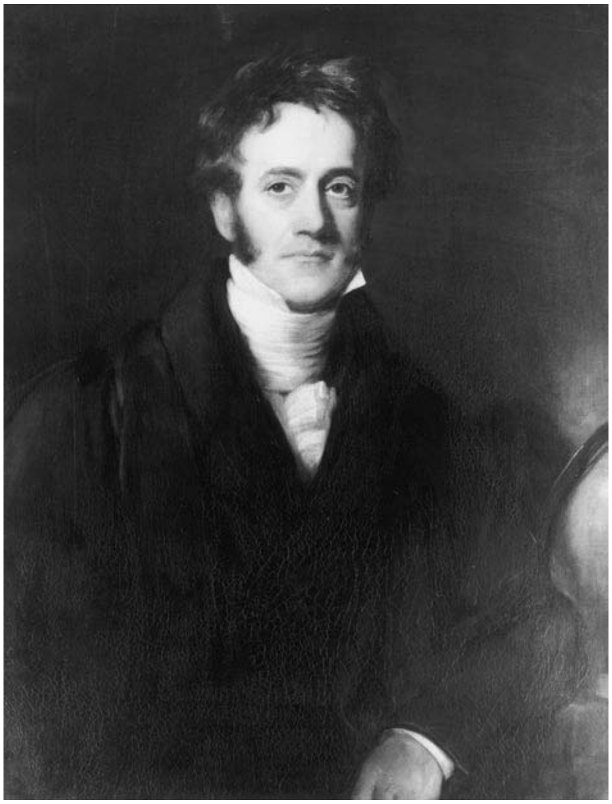
Herschel, John Frederick William

Born **Slough, Berkshire, England, 7 March 1792**
Died **Collingwood near Hawkhurst, Kent, England, 5 November 1871**



One of the best-known natural philosophers of his time, John Herschel supplemented his father's extensive observations of the Northern Celestial Hemisphere by his own campaign to chart the southern sky. John was the only child of **William Herschel** and his wife, Mary Pitt (*née* Baldwin). The family home was the site of the largest telescope in the world, constructed and used by Sir William, assisted by his sister, **Caroline Herschel**, with whom John shared a warm relationship. John was educated at Eton College and private schools. In 1809, he entered Saint John's College, Cambridge, where, with fellow mathematicians Charles Babbage and George Peacock, he formed the Analytical Society to advocate the adoption of continental notation for the calculus. In 1813, Herschel achieved first place (senior wrangler) in the university mathematics degree examination (the *tripos*) and won the Smith's Prize. A mathematical paper submitted through his father to the Royal Society brought him election to a fellowship (on 27 May 1813) at an unusually early age; later mathematical papers yielded the society's highest scientific award, the Copley Medal (1821).

In 1829, Herschel married Margaret Brodie Stewart, daughter of a Scottish Presbyterian divine and Gaelic scholar. The bride, still less than 19 years old, would prove a formidable character and capable partner. The marriage was extremely happy, producing three sons – of whom **John Herschel, Jr.** became an astronomer and **Alexander Herschel** became an astronomer and meteorologist – as well as nine daughters, who mostly married into the more elevated sections of British social and intellectual society.

Searching for a life occupation in his early years, Herschel turned briefly to chemistry, an interest terminated by a failed application for the chair of chemistry at Cambridge. He then tried the law as a profession in London, where he met astronomer **James South**, before returning to Cambridge, first as a subtutor in mathematics. In 1816, when Herschel took his master's degree, he was elected a fellow of Saint John's College; in that same year, his ailing father appealed to John to carry on his work. Before fully doing so, John published extensively on mathematics, light, and chemistry. Treatises on geometrical optics and lens design appeared in encyclopedias and journals. Studies of crystals and physical optics, including polarization and interference, buttressed the adoption of the wave theory of light. Following his father's discovery of infrared radiation, John experimented with practical measures of intensities.

The importance of John Herschel's discovery of the capacity of sodium thiosulphate to dissolve silver salts would be fully realized later in the rise of photography. In the 1820s, the great 40-ft. telescope was falling into decay, because nobody could face the task of polishing and refiguring the main mirror; it lasted long enough to be portrayed in 1830 in the first-ever glass negative photograph.

John took up his father's last project, the discovery and observation of double stars. Originally, William had targeted them in the hope that if a stellar pair consists of one very remote component accidentally nearly aligned with a nearer one, this fortuitous coincidence could help determine the parallax of the nearer star. William's work demonstrated instead that double stars are mostly close pairs gravitationally bound; the goal of extending this project was the discovery of orbital motions. Herschel and South used refractors fitted with positional circles for making observations that led to their catalog of 380 double stars published in 1824, earning them the Gold Medal of the Astronomical Society and the Lalande Prize of the Paris Academy of Sciences. The Astronomical Society, founded in London in 1820 by a group of active astronomers, including John Herschel, met early opposition from the Royal Society of London, but a Royal Charter was granted in 1831.

After William's death in 1822, Caroline retired to her native Hanover, where she remained in vigorous health and in regular correspondence with John until her death. John found time for several extensive Grand Tours throughout Europe, the first with his friend Babbage. Herschel was received with great honors by many of Europe's most famous scientists and astronomers, and climbed many mountains, usually with a *camera lucida*, sketchbook, and also other instruments, such as a barometer.

From 1825 to 1833, Herschel was deeply involved in astronomical observations, using one of the refractors obtained from South and a 20-ft. reflector with 18-in. aperture, still the world's largest telescope. The observations involved a prodigious amount of work, leading to the publication in a series of papers listing a total of 5,075 double stars, arranged in order of right ascension for 1830.0 and North Polar Distance, together with the general catalogue of nebulae and clusters derived from observations covering the whole northern sky using the sweeping survey technique devised by his father. This was updated in 1888 by **John Dreyer** to the *New General Catalogue*, and many galaxies and star clusters are still known by their NGC numbers. John continued to write for popular audiences, on the methods of natural philosophy and on astronomy.

Herschel's mother died in 1832, leaving him free to pursue a long-delayed project – the observation of the sky of the Southern-Hemisphere, thereby supplementing his father's work on the northern sky. The Herschels, their three children, a nanny, and an astronomical assistant embarked in November 1833 for a 2-month voyage to South Africa, during which John made almost every plausible kind of marine, meteorological, and astronomical observation.

At Cape Town, Herschel purchased an estate, where he installed his telescopes. During his 4-year stay, Herschel surveyed the whole southern sky for nebulae and clusters with the 20-ft reflector and for double stars with a refractor. He made detailed studies of the Magellanic Clouds, and of the Orion and η Carinae nebulosities. He also conducted a first effort at precision stellar photometry, in which the brightness of a star seen with the naked eye could be compared with a point image of the Full Moon produced in a steel ball moved to such a distance that the two matched.

In South Africa Herschel measured the intensity of infrared radiation using large-bulb thermometers filled with a dark liquid. He sent a steady stream of short communications to London for publication, including a manual for meteorologists. He made geological and botanical notes, and drawings using the *camera lucida*. Many of these drawings survive, those of plants and flowers often colored by Lady Herschel. He took part in observations of the tides and of the Earth's magnetism. In public affairs, Herschel offered advice on the educational system of the colony.

Herschel was a bulwark in many of the difficult tasks assigned to **Thomas Maclear**, director of the Cape Observatory; a major one was a repetition of the meridian arc measurement of **Nicolas de La Caille** with its anomalous result. Maclear's first reliable assistant was **Charles Smyth**, who arrived at age 16 in October 1835 to begin a brilliant but often eccentric career, deeply influenced by his devotion to Herschel. Though admittedly difficult, the South African years were, according to Herschel, the happiest ones of his life.

Upon his return to England, and eager to accomplish the formidable task of reducing and preparing for publication the results of his African observations, Herschel declined many honors but did accept the presidency of the now Royal Astronomical Society for several years (1839–1841; 1847–1849). A proposal for a reform of the system of constellations with their convoluted boundaries to one based instead on a standard sky coordinate system did not gain general approval until enforced in 1922 by the International Astronomical Union.

In 1839, alerted to developments on the Continent, Herschel engaged in a series of researches in photography and photochemistry that lasted until 1844; it included, among many other investigations, the development of a technique of fixing an image using sodium thiosulphate, the concept of a negative, and the demonstration that the spectrum extends beyond the visible violet. Much of his work dealt with color registration and the use of dyes.

Herschel gave up the Slough residence in 1840, marked by a sentimental farewell to the tube of the great dismantled telescope, and moved to Kent. The South African researches were published in 1847. Diverse activities in science, publication of encyclopedia articles, and affairs of the Royal Astronomical Society fully occupied his time. In 1850, he accepted the office of Master of the Mint, once held by **Isaac Newton**, and unsuccessfully advocated decimalization of the British coinage, getting no further than the introduction of the florin coin, equal to one tenth of a pound. Herschel resigned in 1856 and retreated increasingly into private life, with deteriorating health. He died at his home, Margaret followed him in 1884.

By the time of his marriage, Herschel was already widely celebrated. Shortly thereafter, in 1831, he was accorded the honor of knighthood; on the occasion of the coronation of Queen Victoria in 1838, he was raised to the baronetcy. In South Africa, the site of the 20-ft. reflector was later marked by a commemorative obelisk. Herschel was a member of many scientific societies, and carried on an extensive correspondence with a wide range of people; nearly 15,000 letters are known and summarized. Like many of the greatest figures in English history, he was buried in Westminster Abbey, next to Newton, reflecting the great esteem in which his contemporaries held him.

Several of John Herschel's manuscript diaries and other papers are deposited at the Harry Ransom Humanities Research Center, Austin, Texas.

David S. Evans

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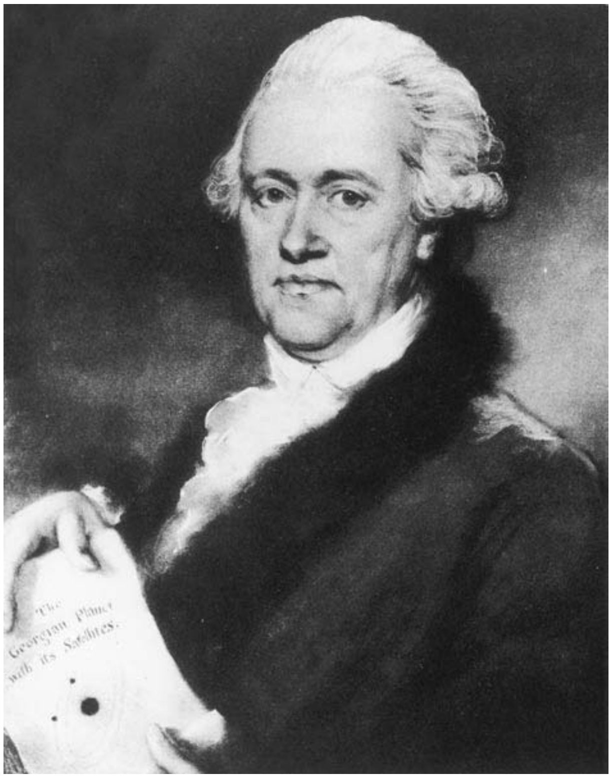
Herschel, (Friedrich) William [Wilhelm]

Born **Hanover, (Germany), 15 November 1738**
Died **Slough, Berkshire, England, 25 August 1822**

As the discoverer of the planet Uranus and the most successful practitioner of the new field of stellar astronomy, Sir William Herschel expanded the scope of the known Solar System and of the Universe beyond it. Herschel was the third of six surviving



children born to Isaac Herschel and Anna Ilse Moritzen. As the son of a Hanoverian Guard bandmaster, William had a musician's upbringing. At age 14, he became an oboist in his father's regiment. Around this time, William's practical talent in music brought him to musical theory and, soon after, he inherited his father's fascination with natural philosophy. So it was that William found himself purchasing a copy of John Locke's *Essay Concerning Human Understanding* while visiting England with his regiment in 1756, a visit that historians agree was a milestone in Herschel's early life.

After Herschel's regiment came under direct fire from the French in 1757, he immigrated to England. Although he arrived with only a French crownpiece in his pocket, by 1766 he had attained sufficient reputation as a musician to secure a position as organist at Bath's Octagon Chapel, where he worked as a performer, teacher, composer, and concert director. According to some accounts, passersby at times spotted Herschel using the intervals between symphony movements to run – in wig, powder, and full concert dress – from the chapel to his workshop, where he continued the experiments that would eventually produce the most powerful reflecting telescopes of his time. In 1772, William's sister **Caroline Herschel** joined him in Bath. With Caroline's assistance, William began his astronomical research in earnest. By the 1780s, these efforts would help him to emerge as one of the most prominent astronomers of his day.

On 8 May 1788, Herschel married Mary Pitt, a wealthy widow, which union brought Herschel both financial security and one son, **John Herschel**, who himself became an accomplished astronomer and natural philosopher. By the time of his death, William Herschel's achievements earned him membership in the Royal Society and election as the first president of the Astronomical Society of London (later the Royal Astronomical Society). He was also offered memberships in the American Philosophical Society and the Academies of Paris, Dijon, Berlin, Saint Petersburg, and Stockholm. King George III appointed Herschel as his Royal Astronomer, and he was awarded knighthood 6 years before his death.

Herschel is best described as a "celestial naturalist" whose methodology mixed diligent observation with, at times, daring speculation. Writing in 1785, he gave the clearest explanation of his approach to astronomy:

> If we indulge a fanciful imagination and build worlds of our own, we must not wonder at our going wide from the path of truth and nature [whereas] if we add observation to observation, without attempting to draw not only certain conclusions, but also conjectural views from them, we offend against the very end for which only observation ought to be made. I will endeavor to keep a proper medium; but if I should deviate from that, I could wish not to fall into the latter error.

In an age when nearly all observational astronomers practiced positional astronomy using refracting telescopes constructed for precision measurement, Herschel built huge reflecting telescopes designed to maximize light-gathering power, resolution, and magnification and intended to provide answers about the nature of the Milky Way and the existence of extraterrestrial life. These huge reflectors, such as the 12-in.-aperture, 20-ft.-focal-length telescope, which was Herschel's instrument of choice during his early career, enabled him to develop the nascent field of stellar astronomy.

In 1779, Herschel commenced a series of "sweeps," observing all stars visible from Bath down to the fourth magnitude. Later "sweeps" included all stars down to the eighth magnitude. These "sweeps" focused special attention on double stars, of which Herschel eventually cataloged 848. His intention was to use the doubles to measure stellar parallax. Although **Friedrich Bessel** would discover a parallax only in 1838, Herschel's own research had immediate consequences. Herschel showed that some doubles, rather than being distant objects near each other in the astronomer's line of sight, are actually gravitationally linked, orbiting their common center of gravity.

During one of Herschel's "sweeps," on 13 March 1781, he sighted what he judged to be a nebulous star or comet (now known to be the planet Uranus). He observed the object throughout the following weeks, convincing himself that he was watching an approaching comet. England's Astronomer Royal, **Nevil Maskelyne**, with whom Herschel corresponded after the initial sighting, suggested that the object was in fact an undiscovered planet. This was confirmed by the Saint Petersburg astronomer **Anders Lexell**, who first calculated Uranus's orbit.

The anonymity that Herschel knew when he first arrived in England quickly faded after the discovery of Uranus. The Royal Society awarded him the Copley Medal for his discovery in 1781, the same year that he was elected to the society. Herschel's suggested name for the new planet, "Georgium Sidus" (George's Star), earned him the attention of its namesake, King George III, who awarded Herschel a £200 annual pension and the title Royal Astronomer. Since the newly created position required that Herschel live nearer Windsor Castle, William and Caroline moved from Bath to Datchet in 1782; in 1786, they settled in Slough. In 1787, King George III gave further support to the Herschels' work by granting Caroline a pension of £50 per year. Herschel also enhanced his income by selling reflecting telescopes to buyers in Britain and on the Continent. Historians agree that few of the telescopes

Herschel sold contributed significantly to the advance of astronomy. The 48-in.-aperture, 40-ft.-focal-length reflector that Herschel completed for himself with the king's support in 1788 remained for decades the largest telescope in existence, although Herschel achieved his greatest successes with more manageable, smaller reflecting telescopes, especially his 18.7-in.-aperture, 20-ft.-focal-length instrument.

Besides his discovery of Uranus, Herschel made other contributions to the astronomy of the Solar System. He presented evidence against claims made by **Johann Schröter** about extra-atmospheric mountains on Venus. He observed and suggested the name "asteroid" for the small bodies that his contemporaries had begun to discover orbiting the Sun between Mars and Jupiter. His studies of Jupiter's four known satellites revealed that, like our Moon, each rotates on its axis once per revolution. Between 1787 and 1789, he discovered Mimas and Enceladus, Saturn's sixth and seventh satellites. In 1787, he discovered the first two satellites of Uranus, Oberon and Titania. Herschel claimed to have discovered four additional satellites orbiting Uranus, but this claim has proven to be spurious. He developed a widely accepted model for the Sun and sunspots, one feature of which was his claim that the Sun is "probably … inhabited, like the rest of the planets." Herschel's early notebooks show that for a period he believed he had observed lunar forests and other evidence of life on the Moon.

The Universe beyond the Solar System gave Herschel's keen eye and active imagination ample room to operate. Herschel set both to work in his investigations of the size, shape, and composition of the Milky Way. In his 1783 "On the Proper Motion of the Sun and the Solar System," Herschel analyzed proper-motion data to suggest that the Sun and its planets are traveling in the direction of λ Hercules. His later papers on the subject calculated the velocity of this movement. Although Herschel's estimated velocities are incorrect, his estimates of the direction of the Sun's motion are quite close to modern values.

In his 1784 paper on the "Construction of the Heavens," Herschel suggested that the Milky Way is a forked slab of stars, in which the Sun lies slightly off-center. Herschel based this claim on his technique of "star gauging." Making the hypothesis that all stars have the same intrinsic brightness, he argued that the dimmest stars are most distant and the brightest are nearest. As a consequence, the overall concentration of stars and the proportion of bright stars to dim stars in any direction approximates the density and depth of space in that direction. As his improved telescopes penetrated deeper into space and revealed stars not seen in earlier gauges, Herschel departed from the forked-slab model. But both his model and his method were improvements over the primarily conjectural disk theories of the Milky Way that Herschel's generation inherited from **Thomas Wright**, **Immanuel Kant**, and **Johann Lambert**.

Some of Herschel's most innovative research regarded the "nebulae"– a general term at that time for what are today recognized as reflection nebulae, HII regions, planetary nebulae, open and globular clusters, and galaxies. Although only a hundred such objects were known when Herschel began to observe them, he discovered and cataloged over 2,400 more and brought them to a central position in his cosmology. Initially, Herschel believed that most nebulae are resolvable into individual stars; in fact, during the mid-1780s, he concluded that most are, in effect, comparable in nature and size to our Milky Way system. A 1785 paper corroborated this claim by suggesting that Newtonian gravitational theory is sufficient to explain the conglomeration of individual stars into clusters. Herschel backed away from his stance on the resolvability of nebulae and the existence of island universes in his 1791 paper "On the Nebulous Stars, Properly So-Called." Here, Herschel discussed his observations of a planetary nebula, arguing that, rather than being resolvable into individual stars, it must consist of a central star surrounded by a "shining fluid." This "shining fluid" entered the heart of his cosmology and cosmogony in an 1811 publication, "Astronomical Observations Relating to the Construction of the Heavens." In this study, Herschel suggested that most nebulae, rather than being composed of thousands of stars, consist of clouds of "shining fluid" gradually condensing into individual stars.

Although Herschel had by 1811 backed away from his earlier (and correct) belief that some nebulous objects are island universes independent of the Milky Way, his exhaustive observations, extensive catalogs, and careful speculations regarding the stars and nebulae were enough to lay firm foundations for cosmology and stellar astronomy. The latter field, although it scarcely existed before Herschel made it central to his research, eventually emerged as the dominant discipline of modern astronomy.

Michael J. Crowe and *Keith R. Lafortune*

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Hertzsprung, Ejnar [Einar]

Born **Frederiksberg near Copenhagen, Denmark, 10 October 1873**
Died **Roskilde, Denmark, 21 October 1967**

Danish astronomer Einar Hertzsprung gave his name to the Hertzsprung–Russell diagram of stellar luminosities versus temperatures, a primary tool in studying the evolution of stars, and to the

Hertzsprung gap in that diagram between main sequence and giant stars, representing the very rapid change that occurs when stars first exhaust their central supply of hydrogen fuel. He was the son of a director of a Danish state life insurance company who had originally taken a degree in astronomy at Copenhagen University.

Hertzsprung completed a degree (after his father's death in 1893) in chemical engineering at Copenhagen Polytechnic Institute in 1898 and proceeded to work for the Danish company Hoffding in Saint Petersburg. In 1901, he returned to academe and began work at Leipzig University on photochemistry with Wilhelm Ostwald. The death of his brother the next year brought Hertzsprung back to Copenhagen to live with his mother and to begin investigations of applications of photography; he began work at both Copenhagen University Observatory and at the private Urania Observatory of Victor Nielsen. In 1905 and 1907 he published two papers "Zur Strahlung der Sterne" (on the radiation of stars), in which he had used stellar colors determined from his own work and distances estimated from proper motions to show that stellar brightnesses, particularly for the cool stars, came in two groups, which he called "Riesen"(giants) and "Zwerge"(dwarfs). About a year later, **Henry Russell** made the same discovery, using luminosities derived from his own parallax measurements, and a plot of star brightness (apparent or absolute magnitude) versus spectral type (or color or temperature) is now called a Hertzsprung–Russell diagram.

Becoming aware of Hertzsprung's work, **Karl Schwarzschild**, then director at Göttingen Observatory, appointed him to a position there in 1909. They moved together to Potsdam the same year. Hertzsprung was appointed to an extraordinary professorship and associate directorship at Leiden under **Willem de Sitter** in 1919, and succeeded him as ordinary professor and director in 1935. He retired in 1944, was succeeded by **Jan Oort,** and returned to Denmark after World War II, living in the small village of Tollose near the Brorfelde site of the Copenhagen Observatory.

Hertzsprung continued to measure orbits of binary stars and carry out other astronomical work until about 3 years before his death, when he transferred his measuring engine to the observatory, saying that he could no longer keep up with his former students. There were many, including **Kaj Strand**. Hertzsprung's last journey abroad was in 1964, to participate in a symposium in his honor, at which the work of his former students fully justified his view that a beginning astronomer should get acquainted with as many different methods of observing as possible before choosing a specialty.

Hertzsprung's recognition of very bright supergiants in 1905 served to validate the spectroscopic criterion ("c trait") identified by **Antonia Maury** and denied by **William Pickering**. His most productive years were probably the 1909–1919 Potsdam period, during which he discovered the variability of Polaris and recognized it as a Cepheid variable of small amplitude (1919), plotted the first color-magnitude diagrams for the Pleiades and Hyades star clusters (1911), and used the period-luminosity relation for Cepheid variables, discovered by **Henrietta Leavitt**, to estimate the distance to the Large Magellanic Cloud. He observed at Mount Wilson Observatory in 1912 and used plates of the Pleiades taken there to show that there was a very tight sloping relation between color and luminosity for most of the stars, but that the ten brightest all seemed to be the same color and that those fainter than eighth magnitude were again all the same (much redder!) color. These effects are now understood in terms of saturation of blue colors by a black-body spectrum at high temperature and molecular absorption in very cool stars.

After the move to Leiden, Hertzsprung published accurate colors for northern stars brighter than fifth apparent magnitude and used their proper motions to estimate their distances. The plot of brightness versus color revealed a gap between blue and red stars for the brightest ones, which is now attributed to rapid evolution through this Hertzsprung gap. He and Russell independently discovered a statistical way of estimating dynamical parallaxes (distances) for binary stars at about the same time. Each always spoke very highly of the other's work. Hertzsprung spent the observing seasons of 1923/1924 and 1930/1931 in South Africa recording light curves of variable stars. By chance in the process he discovered the first of what he called "flare stars," DH Carinae. The light curves led him to discover a relationship between long periods and very asymmetric light-curve shapes and to recognize bumps on the descending light curve of Cepheids, which can be used to estimate their masses.

Hertzsprung maintained an interest in the Pleiades to and beyond his retirement, showing, for instance, that the neighboring dust clouds reflect at most 5% of the light incident on them from the stars. His astrometric work helped to define the location of the galactic poles. Most of Hertzsprung's later work focused on measuring orbits of long-period visual binaries, and he was among the first to recognize that stars also come in triple and higher-order systems.

Honorary degrees from Utrecht, Copenhagen, and Paris recognized his work. Hertzsprung received the Bruce Medal of the Astronomical Society of the Pacific and both the Darwin Lectureship and the Gold Medal of the Royal Astronomical Society (London). He was active in five different commissions of the International Astronomical Union, and the city of Copenhagen awarded him its Ole Römer Medal.

Dieter B. Herrmann
Translated by: *Balthasar Indermühle*

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Herzberg, Gerhard

Born **Hamburg, Germany, 25 December 1904**
Died **Ottawa, Ontario, Canada, 3 March 1999**

Gerhard Herzberg is widely regarded as the founding father of modern molecular spectroscopy. His textbook *Atomic Spectra and Atomic Structure* was first published in 1935, and the trilogy *Molecular Spectra and Molecular Structure*, Vol. I *Diatomic Molecules* (1939), Vol. II *Infrared and Raman Spectra of Polyatomic Molecules*

(1945), and Vol. III *Electronic Spectra and Electronic Structure of Polyatomic Molecules* (1966), has become the "bible" for generations of astronomers, physicists, and chemists. Herzberg received the 1971 Nobel Prize in Chemistry "for his contributions to the knowledge of electronic structure and geometry of molecules, particularly free radicals." In recognition of Herzberg's interest and contribution to astrophysics, the Herzberg Institute of Astrophysics was established in 1975 by the National Research Council of Canada. The headquarters of the institute is located at the Dominion Astrophysical Observatory, Victoria, British Columbia.

Herzberg was born in a middle class family in Hamburg, Germany, the second son of Franz Otto Herzberg and Anna Sophia Christina Kürsten. When he was 10 years old his father died, and he lived a frugal life. Adolescent Herzberg aspired to be an astronomer but being told by the director of Hamburg Observatory, "There is no point in thinking of a career in astronomy unless one has private means of support," he enrolled in the Engineering Physics program of the Darmstadt Institute of Technology in 1924. Those were the great years when the newborn quantum mechanics unraveled the mysteries of the microscopic world with phenomenal speed. After receiving a doctor's degree in 1928 and working in Göttingen and Bristol as a postdoctoral fellow, Herzberg started his own laboratory in Darmstadt in 1930 and quickly established himself as a leader in molecular spectroscopy. His contributions to the foundation of spectroscopy are numerous, but here only his work directly related to astronomy is discussed.

In 1935 Herzberg left Germany to escape Hitler's Nazi regime and started his laboratory at the University of Saskatchewan, west Canada. In the summer of 1941 he attended a meeting at the Yerkes Observatory of the University of Chicago that was devoted to the problem of the recently discovered interstellar spectra. CH and CN spectra had already been identified by **Andrew McKellar**, but there remained an unexplained progression of four sharp lines observed by **Walter Adams** at Mount Wilson Observatory. Herzberg discussed this spectrum with **Edward Teller**, and they came to the conclusion that the spectrum is likely due to CH^+. Herzberg and his student Alex Douglass found the spectrum in their laboratory plasma of benzene–He gas mixture and, from its rotational structure, confirmed the CH^+ hypothesis. This was the first molecular ion identified in interstellar space.

Herzberg's second astrophysical contribution during the Saskatchewan period was also laboratory spectroscopy of carbon-containing species. The 4050 Å emission line had been known in comets since its discovery by **William Huggins** in 1881, but its carriers were not identified. In 1942, Herzberg reproduced the spectrum in the laboratory but misidentified it as due to CH_2. The correct identification of the spectrum as due to the carbon chain free radical C_3 was done in 1951 by Douglass.

In 1945 Herzberg started his new spectroscopic laboratory at the Yerkes Observatory. His office was across the corridor from **Subrahmanyan Chandrasekhar**'s, and they became close friends. Herzberg constructed a long pathlength multiple-reflection spectrometer and took near infrared spectra of CO_2 mimicking the atmosphere in Venus and CH_4 (in Jupiter). His most influential work during this period was the discovery of the electric quadrupole spectrum of H_2. Using a long pathlength of 6 km (!) and a high pressure of 10 atm, Herzberg detected the very weak first ($v = 2 \leftarrow 0$) and second ($v = 3 \leftarrow 0$) overtone absorption of H_2 on photographic plates. The quadrupole spectrum of H_2 was later extended to the fundamental ($v = 1 \leftarrow 0$) band by D. H. Rank (1965) and to rotational spectra by J. Reid and McKellar (1978). Its emission spectrum has become a very powerful astronomical probe to study hot objects such as planetary ionospheres, planetary nebulae, circumstellar gas, superluminous galaxies, *etc*. The fundamental band also has been observed in absorption in dense molecular clouds providing the H_2 column densities directly.

In 1948 Herzberg moved to the National Research Council of Canada in Ottawa (as director of the Division of Physics from 1949 to 1955) and initiated his new laboratory that was to become a "mecca" for generations of young spectroscopists. He was promised complete freedom of research and abundant budget and personnel. His first astrophysical work in the new laboratory was the identification of H_2 in the atmospheres of Neptune and Uranus (1952), which marked the first observation of extraterrestrial hydrogen molecules. This work was based on the 1949 observation by **Gerard Kuiper** of a diffuse feature at 8270 Å, and the laboratory spectroscopy of the pressure-induced H_2 spectrum by H. L. Welsh (1949). Using a long pathlength of 80 m filled with H_2 to a pressure of 100 atm at 78 K, Herzberg identified the line as due to the pressure-induced $v = 3 \leftarrow 0$ second-overtone band of H_2.

Using the novel technique of flash photolysis, Herzberg's group in Ottawa discovered spectra of many free radicals of astrophysical interest. They are chemically active, unstable species and are rare in terrestrial environments but may exist abundantly in astronomical objects. Herzberg himself discovered the methyl radical CH_3 (1956) and methylene radical CH_2 (1959), the most fundamental organic radicals, and this made a strong case for his Nobel Prize. These radicals have recently been observed in planets and interstellar space, where they play important roles as reaction intermediates for production of more complicated organic molecules.

Later in his life, Herzberg was greatly interested in the problem of the diffuse interstellar bands. These many strong and broad absorption lines have been observed in all directions of the sky, from violet to near-infrared, for over 100 years, but their carriers are yet to be identified. Herzberg speculated that the large spectral widths are due to short lifetimes of the absorbers in their electronic excited states because of predissociation. While this exact mechanism may not be correct, it excited his interest in spectroscopy of fundamental polyatomic ions such as H_3^+ and CH_4^+. In 1974 Herzberg and H. Lew discovered H_2O^+ in the spectrum of the tail of comet C/1973 E1 (Kohoutek) based on their laboratory spectrum obtained 2 years earlier. Although comets had been believed to be composed mainly of ice since **Fred Whipple**'s proposal in 1950, this provided the first direct observational evidence of the presence of a large amount of water in a comet.

Besides the Nobel Prize, Herzberg received a number of honors both before and after in Canada, England, and the United States.

Since the beginning of spectroscopy and astrophysics (**Joseph von Fraunhofer**, 1817), spectroscopists have often been astronomers and *vice versa*. Gerhard Herzberg, together with Charles Townes (winner of the 1964 Nobel Prize in Physics for formulation of the principles of the MASER), personifies this fine tradition.

Takeshi Oka

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Hesiod

Flourished **possibly Ascra, Boeotia, (Greece), *circa* 8th century BCE**

Hesiod greatly influenced later classical thought and literature by establishing a cosmological foundation for the mythic past, by associating astronomical observation with a practical calendrical system, and by establishing a precedent for the use of astronomical references in later classical literature. One of the earliest Greek poets, he composed epic and didactic verse, perhaps drawing from oral traditions, around 700 BCE. What little can be ascertained about his life comes from his surviving works although such a representation may be a traditional persona adopted by the poet. Nevertheless, Hesiod says that his father had given up an unsuccessful seafaring mercantile livelihood in Cyme on the western coast of Anatolia and moved to Ascra in Boeotia on the Greek mainland. The poet portrays himself as tending sheep nearby on the slopes of Mount Helicon, where he says he was inspired by the Muses to compose verse. He also claims to have won a prize for poetry in a competition at Chalcis on the island of Euboea, indicating that he was influenced by an active tradition of bardic recitation in the region. According to ancient authorities, Hesiod's literary output was large, addressing a wide variety of subject matter.

Despite Hesiod's enormous influence, however, only two surviving works can be ascribed to him with certainty. The earlier, the *Theogony,* recounts the origins of the Universe, the descent of the gods, and the eventual establishment of the present order. It exhibits strong influences from eastern cultures, among them the Hittites, the Hurrians, the Phoenicians, and the Babylonians. Cosmogonic aspects appear early in the work. After an invocation to the Muses (1–115) the poet describes the beginnings of things, relates the origins of the material Universe and identifies several primal forces. First Chaos, the gaping Void, comes into being; followed by Gaia, the Earth; Tartaros, the dark and lowest part of the Earth; and Eros, the creative principle of Attraction that causes all things to coalesce. Gaia, the primordial generative source, then parthenogenetically bears Ouranos, the sky, to cover herself and to be the home of the gods (126–127). This Hesiodic perception of the earth-covering heavens becomes even more evident some lines later (176–177) as Ouranos spreads himself over Gaia to mate, bringing with him nocturnal darkness. Indeed, his traditional epithet (*asteroeis* "starry") associates him with the dark night sky itself, even though at this point in the narrative neither the stars nor any celestial bodies have yet come into existence. Hesiod later (375–383) completes the genealogy of celestial objects and describes the later descendants of Ouranos – the Sun (Helios), Moon (Selene), Dawn (Eos), and the stars themselves, fathered with Eos by the aptly named Astraios. According to the poet, the shining stars crown the sky and have as their sibling the planet Venus (Eosphoros, "bringer of dawn"), the only planet mentioned in Greek literature before the Classical Age.

The *Works and Days* offers more astronomical material. Much of the poem consists of moral advice directed primarily at the poet's brother Perses, himself perhaps a literary fiction. The work comprises two sections – the first and longer part (the "Works") includes practical instruction on agriculture, sailing, and a wide range of social and religious activities; the latter and much shorter part (the "Days") is an almanac for performing a variety of tasks.

In the former, astronomical information reveals a contemporary familiarity with specific stars and constellations (most of them the same as those known to **Homer**), with their regular rising and settings (phases) throughout the year, with the concept of solstices, and with perceived celestial influences on human society. Hesiod includes these observations in a lengthy overview of farming activity (381–617) and of sailing (618–694). The Pleiades indicate the time when specific farm tasks are to be done based on the asterism's heliacal (dawn) rising in May (reaping) and its setting in October (plowing); Hesiod also includes the setting of the Hyades in the latter passage. The heliacal rising (June) and setting (November) of Orion indicate the times for threshing and plowing, respectively; its setting also accompanies the storminess of the winter when the poet advises against seafaring. Arcturus is also important – at its sunset (acronycal) rising in February, the vines are to be pruned, with both Orion and Sirius at the sky's midpoint; at its heliacal rising (September), the vintage begins. Furthermore, when Sirius shines through much of the night (September), the rainy season arrives and woodcutting should begin. The star's heliacal rising in late July, moreover, increases lust in women while sapping men of their virility, presumably because it rises with the Sun and remains above the horizon all day. This perception indicates a tendency, perhaps rooted in folk traditions, to acknowledge a tangible astral influence upon human affairs that goes beyond the simple calendrical formula based on celestial observation.

The *Works and Days* also reveals a knowledge of the solstices ("turnings of the Sun"). The poet mentions them three times – when the rising of Arcturus is said to occur 60 days after the winter solstice (564–567), when the poet advises against plowing at that time of year (479–480), and when the sailing season is said to begin 50 days after the summer solstice (663–665). Hesiod, on the other hand, makes no specific mention of the equinoxes, even though **Pliny** suggests otherwise. Nevertheless, Hesiod has established a recognizable system of timekeeping, although his calendrical year is by no means entirely astronomical. Including other indicators from the natural world, it is primarily agricultural and designed for practical applications.

Despite the essentially prescientific nature of Hesiod's calendar, his subsequent influence was considerable, with later developments drawing on his early steps. According to ancient authors he was also the author of a lost work, the *Astronomia,* of which several fragments survive and whose contents were presumably about constellations and their stories. In literature, too, Hesiod was influential. The lyric poet Alcaeus incorporates the account of Sirius's effects on humans into his own work as does the author of the Pseudo-Hesiodic *Shield of Heracles*. Echoes of and allusions to Hesiod are found in Callimachus and **Aratus**, while **Virgil** rightly calls his own *Georgics* "an Ascraean poem" because of its debt to Hesiod's *Works and Days*.

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Hess, Victor Franz [Francis]

Born **Waldstein, (Austria), 24 June 1883**
Died **Mount Vernon, New York, USA, 17 December 1964**

Austrian–American experimental physicist Victor Hess shared the 1936 Nobel Prize in Physics (with **Carl Anderson**) for his 1912 discovery of cosmic rays, meaning the discovery that the primary source of ionization of the Earth's atmosphere was coming from above (not from radioactive rocks or other terrestrial substances) and was not associated with the Sun. The actual name cosmic rays was suggested in 1925 by **Robert Millikan**.

Hess's father was the chief forester for the estate, centered on Schloss Waldstein, of Prince Oettingen-Wallerstein. After attending Gymnasium near Graz, Hess attended the University of Graz (1901–1906) from which he graduated *summa cum laude* with a Ph.D. in physics. His plans for postdoctoral studies in optics under Paul Drude at the University of Berlin were interrupted by Drude's suicide, Hess went to the University of Vienna to study under Franz Exner and Egon von Schweidler, pioneers in atmospheric electricity, radiation, and radioactivity. From 1910 to 1920 Hess worked as *Privatdozent* (lecturer) at Grax, an assistant professor at the Institute for Radium Research of the Austrian Academy of Sciences, and lecturer in physics at the Vienna Veterinary College. In 1921 he came to the United States for 2 years to serve as director of the United States Radium Corporation in New Jersey. During that time he was also a key consulting physicist to the United States Bureau of Mines (Department of the Interior). In 1923 he returned to Graz as full professor of physics; in 1929 he became dean of the faculty. In 1931 Hess was named director of the Institute for Radium Research at Innsbruck. In 1938, however, shortly after the German annexation of Austria, Hess suddenly lost all his positions – whether because his wife was Jewish, he had been a supporter of Chancellor Kurt von Schuschnigg's independent government, or (perhaps) of his own strong commitment to Roman Catholicism, is uncertain. In any case, threatened by the Gestapo and fearing that he would end up in a concentration camp, Hess and his wife escaped to Switzerland from where they immigrated to the United States. Hess was immediately offered a post as professor of physics at Fordham University in New York, where he remained until his retirement. Hess became a naturalized citizen in 1944.

In a series of groundbreaking experiments with atmospheric balloons starting in 1911, Hess proved that "a radiation of very high penetrating power enters our atmosphere from above." This radiation from outer space explained the mystery of why air in electroscopes (used to detect electrical charges) became ionized regardless of how well they were insulated and eventually led to Anderson's discovery of the positron. Previous theories had tried to explain the ionization with terrestrial radiation from radioactive minerals. There was contradictory data, such as Theodore Wulf's measurements at the top of the Eiffel Tower in 1910 showing more, not less, radiation at the top (at about 300 m). Yet it was not until Hess's spectacular balloon ascents, which required new instruments of his own design (in earlier attempts the instruments had failed) that were impervious to the temperature and pressure changes, that the answer became clear: The radiation increased with altitude; after several miles it was many times greater than at ground level.

Still more remarkable was the fact that the radiation levels did not decrease during a solar eclipse or show any significant day/night asymmetry. This showed that the main source of the radiation came not even from the Sun but from deep space. It was for this discovery that Hess was awarded the Nobel Prize. Hess actually ascended with his equipment, to a maximum height of 5,350 m, probably a record for a practicing physicist until the confirming 1913 balloon studies by **Werner Köhlhorster**.

Besides his numerous contributions to European and American scientific journals, Hess wrote several books, including *Luftelektrizitaet* (Atmospheric electricity, coauthored with H. Benndorf, Braunschweig, 1928), *The Electrical Conductivity of the Atmosphere* (Akademie, 1934), and *Die Weiltstrahlung und ihre biologische Wirkung* (Cosmic Radiation and its Biological Effects, coauthored with Jakob Eugster, revised edition, Fordham University Press, 1949). His 1947 article in the *Journal of Roentgenology and Radium Therapy*, coauthored with William McNiff, is especially significant in that it presents for the first time their integrating γ-ray method for detecting radium poisoning in the human body. (The previous year, Hess and Paul Luger had conducted the first tests for fallout in the United States after the Hiroshima atomic bomb.) Subsequently, Hess led a team of scientists in a United States Air Force study to determine the radiation effects of atomic bomb tests. Hess was particularly sensitive to the possibility of radiation damage, having had his own thumb amputated in 1934 as a result of accidental exposure during his Innsbruck years.

Among his other honors, Hess received honorary degrees from Vienna (an MD!), Fordham, Chicago, Innsbruck, and Loyola (a testament to his ongoing Catholicism) universities and awards from American, Austrian, and German organizations; he was a member of the Papal Academy of Sciences as well as the Austrian Academy of Sciences.

Daniel Kolak

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Hevel, Johannes

Born **Danzig, (Gdańsk, Poland), 28 January 1611**
Died **Danzig, (Gdańsk, Poland), 28 January 1687**

Johannes Hevelius excelled as an observer and instrument builder. His publications were complete in their discussion of historical background, methodology, and instrument design in addition to the actual observations, but are generally found wanting in a theoretical sense. With his second wife, **Elisabetha Hevelius**, he engraved an atlas well known for its beauty and for the addition of seven new constellations, of which four survive under the International Astronomical Union's modern standards.

Abraham Höwelcke, a prosperous Danzig brewer and property owner, and his wife, Cordelia (*Née* Hecker) gave birth to 10 children, of whom Hevelius was the second. The family name is seen in as many as seven forms in addition to Höwelcke, most often as Hevel or Heweliuza. Johannes adopted the Latinized version of Hevelius as a matter of personal choice. In this privileged family, Hevelius received an excellent education at the local Gymnasium until it was closed. For a period, he studied in Bromberg, Poland, where he was a student of mathematician and astronomer Peter Krüger. In addition to the customary training in these subjects, Krüger devoted special attention to Hevelius in extra sessions on practical observational astronomy, and encouraged him to learn instrument-making and engraving, all of which Hevelius applied well in his later years.

At age 16 Hevelius returned to Danzig to complete his training at the newly reopened Gymnasium. Acceding to the wishes of his parents that he prepare for a career in public service, Hevelius sailed from the old Hanseatic port to the Netherlands at the age of 19 years, but found it difficult to exclude astronomy from his thoughts as he observed a solar eclipse *en route*.

Hevelius studied jurisprudence at the University of Leiden in 1630 and 1631. He then traveled on to England, where he improved his English somewhat and published his observations of the eclipse in the *Philosophical Transactions of the Royal Society*. Moving to France, Hevelius became acquainted with **Pierre Gassendi** and **Ismaël Boulliau** in Paris and **Athanasius Kircher** in Avignon. However, he cancelled a planned trip to Italy to visit **Galileo Galilei** and **Christoph Scheiner** when his parents called him home in 1634. Once home, Hevelius settled into the routine of his family's brewing business and began a career in public service as a councilor in his native town. In 1635, he married Katharina Rebeschke, the daughter of another wealthy Danzig merchant. The couple remained childless, but Katharina was an active partner in the marriage, assisting in the management of the brewery to free Hevelius's time for participation in civil affairs and pursuit of his other interests.

Having largely ignored astronomy after leaving Paris, Hevelius visited his former mentor Krüger in 1639, shortly before the latter died. Although throughout his life he took a leading part in municipal affairs, the visit to Krüger was probably instrumental in the fact that from then on Hevelius's chief interest centered on astronomy. He established an observatory, which he called Stellaburgum, on the roof of his Danzig home. The platform gradually expanded until it covered three adjacent buildings. It supported shelters for some of his instruments and his printing press. Hevelius divided his time between observing and supervising the construction of astronomical instruments. Caught up in the drive to improve refractor performance by reducing color dispersion and spherical aberration, in 1641 he built a telescope with a focal length of 50 m. With the lens mounted on a spar suspended with ropes from a 25-m mast, the telescope was a failure. Other refracting telescopes of more conventional design were, however, successful, as evidenced by Hevelius's reported selenographical investigations. In these, and in his later efforts, the Polish crown supported Hevelius financially; Stellaburgum was visited by both King Jan II (Casmir), and King Jan III (Sobieski).

Hevelius observed sunspots from 1642 to 1645 with sufficient thoroughness to derive a rotational period for the Sun, but his main interest devolved to charting the lunar surface. Although previous maps of the Moon had been published, notably those of **Francisco Fontana**, Claude Mellan (working for **Pierre Gassendi** and **Nicolas de Peiresc**), and **Michael van Langren**, Hevelius's project was more ambitious than those previous efforts. He prepared 40 engravings representing the Moon in various phases. His maps included three Full Moon illustrations with maps of the libration zones appended, the first such recognition of an effect that apparently confused earlier selenographers. Hevelius likely benefited in that regard from his construction of a lunar globe that permitted him to depict both the longitudinal and latitudinal librations. He published his maps in *Selenographia sive Lunae Descriptio* (1647), a work in which the lunar maps were usefully supplemented with a description of the current state in observational astronomy. Hevelius started with the art of making lenses, a discussion of optics, and other aspects of telescope making. He included his sunspot observations and extensive comments on the planets. In effect, the reader of *Selenographia* received a full discourse on the state of astronomical practice in the middle of the 17th century. The maps themselves would have entitled Hevelius to be called the founder of lunar topography. However, *Selenographia* was widely read and admired by contemporary astronomers for all these other resources as well.

Special mention should be made of the discussion of the satellites of Jupiter in the *Selenographia*. In that section, Hevelius confronted a 1643 claim by **Antonius de Rheita** that the latter had discovered five new satellites of Jupiter. Hevelius had been observing the planet at the same time and showed, by plotting both the satellites and the surrounding stars in the constellation of Aquarius, that the satellites that Rheita had claimed to discover were really fixed stars in the constellation. Anyone could still observe the same stars in Aquarius although Jupiter had moved away from the constellation. In the process, Hevelius established an effective standard of evidence for future discoveries.

Between 1652 and 1677, Hevelius observed many comets, some of which might be credited to him as "discoveries" in more modern times. However, the difficulties of communication between astronomers in the 17th century make such priority claims meaningless. Hevelius's comet observations, published in *Cometegraphia* in 1668, have proven valuable to modern studies of comet orbits. His parallax observations indicated that the orbits of comets were well beyond the orbit of the Moon. However, there is little evidence to support suggestion that he understood that comets followed parabolic tracks round the Sun. Hevelius did include, as the frontispiece of *Cometegraphia,* an engraving showing himself pointing to a curved comet path in order to contrast his views allegorically to those of **Aristotle**, who described comets as sublunary, and **Johannes Kepler**, who believed they traveled in a straight line.

In 1662, Katharina died after 27 years of marriage, management of the Hevelius household, and assistance with brewery management. Within a year, Hevelius remarried, this time to Catherina Elizabetha Koopman, a 16-year-old beauty with a burning desire to participate in his astronomical pursuits. Their productive collaboration over the next 26 years is frequently cited as a model scientific/marital relationship similar to that of **William** and **Margaret Huggins**. In the case of Johannes and Elizabetha, however, three daughters blessed their union and lived to maturity.

One odd aspect of Hevelius's career in both telescope building and observation came to a head in 1679 when a dispute with **Robert Hooke** and **John Flamsteed** flared. Although Hevelius had been an early practitioner of telescope building and used them for many of his observations, he resisted the application of telescopic sights to his stellar position-measuring devices. He held this opinion even though nearly all other astronomers had changed their practice. Considering himself an observer in the tradition of **Tycho Brahe**, and perhaps fearing that a change so late in life would compromise the value of his extensive observations without such devices, Hevelius refused to accept the new concept. He declared that his observations with naked eye sights were as accurate as any made with telescopic sights. In an effort to resolve the dispute, the Royal Society dispatched young **Edmond Halley** to Danzig to compare observations with telescopic sights with those made simultaneously by Hevelius. While Halley was impressed with the accuracy of Hevelius's instruments and techniques, retrospective comparisons of their results generally show a slight advantage for the telescopic sightings in both accuracy and precision.

On 26 September 1679, a fire destroyed the Hevelius home and observatory, instruments, and many of his books and manuscripts. With the help of King Jan III and many others, Johannes and Elizabetha promptly rebuilt the observatory, though with less elegant instrumentation, so that by December 1680 he was able to observe the great comet C/1680 V1. His observations on the variable star "Mira," which he named, are included in *Annus climactericus* (1685).

After Johannes died, Elizabetha completed the editing of a catalog of over 1,500 stars and saw it through publication as *Prodromus astronomiae* (1690). When **Francis Bailey** reduced the Hevelius catalog and published it in the *Memoirs of the Royal Astronomical Society* in 1843, he explained that the catalog was essentially ready for submission to the publisher at the time of Johannes's death, implying that Elizabetha's role in the effort was *de minimus*. Given Johannes's failing health in his later years, however, it is more likely that Elizabetha carried or at least shared the burden of the preparation and editing of the catalog.

In an atlas of 56 sheets entitled *Firmamentum Sobiescianum sive Uranographia* (1690), there are delineated seven new constellations. One of the constellations (Scutum Sobieski, now known as Scutum) was named in honor of the king who had helped the Heveliuses so significantly in their later years. Elizabetha personally dedicated the atlas to Sobieski.

In 1664, Hevelius was elected to full membership in the Royal Society in London.

Fathi Habashi

Alternate name

Hevelius

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Hevelius

Hevel, Johannes

Hevelius, Catherina Elisabetha Koopman

Baptized **Danzig, (Gdańsk, Poland), 17 January 1647**
Buried **Danzig, (Gdańsk, Poland), 23 December 1693**

Catherina Hevelius assisted her husband, Danzig brewer and politician **Johannes Hevel**, with his astronomical observations, data reduction, and atlas engraving, and published their important work after his death. The daughter of a wealthy Dutch merchant, Nicholas Koopman, and his wife Joanna (*née* Mennings), Catherina Elisabetha was well educated for a young woman of her time. In the course of acquiring that education, she apparently developed a strong interest in astronomy before the age of 16 years and may have visited the Hevelius household and observatory. Hevelius's first wife, Katharina (*née* Rebeschke), also the daughter of a wealthy Danzig citizen, had managed her husband's household and helped with the brewery business to provide him time for civic involvement and astronomy, but she was not interested in astronomy. Katharina died in 1662.

After her marriage to Johannes in 1663, Catherina Elisabetha referred to herself as Elisabetha, likely out of respect for his first wife. It seems possible that, as feminist historians of science assert, Elisabetha married Hevelius, 36 years her elder, in order to further her own interest in astronomy, but it also seems likely that her interest was welcomed by the older astronomer. Elisabetha not only managed the Hevelius household but also acted as his assistant in making and reducing observations, compiling a catalog, and preparing an atlas reflecting those results. In addition to all this, whereas Johannes's first marriage was childless, Elisabetha bore him three daughters, all of whom lived to maturity, and one son who died as an infant.

In September 1679, a fire destroyed the Hevelius home and observatory in Danzig while the family was at their country home. All of the astronomical instruments were destroyed, though some of his valuable library and correspondence were preserved. Most 68-year-old individuals would find such a catastrophe had ended their working career when it destroyed the fruits of their labor. With Elisabetha's help, however, Johannes restored his observatory within 2 years and continued to work, albeit with reduced capacity, until his death in 1687.

By then, Elisabetha had worked with her husband for 24 years. She edited and published two of his great works posthumously. One was a catalog of their observations of 1,564 stars (*Prodromus astronomiae*, 1690), while the other was an atlas of 56 plates showing individual constellation figures (*Firmamentum Sobiescianum*, *siva Uranographia*, 1690). In the atlas, a number of new constellations had been invented by the Heveliuses, the most famous of which was the small constellation of Scutum Sobieskii or Shield of Sobieskii with which they honored the Polish king and acknowledged the substantial financial assistance he rendered for the reconstruction of their home and observatory. John North comments that it is possible that some of the plates for the atlas had been engraved by Johannes before his death, but that leaves open the remainder of the plates including the addition of the new constellations. P. V. Rizzo attributes the new constellations to Elisabetha on the basis of such logic, but there is no evidence to support that view.

Thomas R. Williams

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Hey, (James) Stanley

Born **Nelson, Lancashire, England, 3 May 1909**
Died **probably in Eastbourne, Sussex, 27 February 2000**

English radar and radio astronomer Stanley Hey led the small groups that made three of the four first discoveries in radio astronomy – emission from the Sun, radar reflections from ionized trails of meteors (hence daytime meteor showers), and the first extragalactic discrete radio source, Cygnus A.

Hey studied physics at Manchester University, where he met and married a fellow student, Edna Heywood, and received a master's degree in 1931 in X-ray crystallography. After a period of high-school teaching, the outbreak of World War II led him to take a 6-week course in radar and to join the Army Operations Research Group [AORG]. Here a superior officer once referred to him as James Hey, a misnomer which survives today in many reference works (including this one).

In early 1942, the AORG was focusing on ways to counteract the increasing ability of German stations on the northern French coast to "jam" the protective chain of radars on the home side of the English Channel. On 27 and 28 February about 10 anti-aircraft gun-laying radar sites, widely scattered around the coast, reported excessive noise-like interference that could not be "tuned out," that is, it was found over the whole range of operating frequencies even though there were no enemy raids on those days. When Hey compared all reported azimuths with those of the Sun over the day, the agreement was striking. The clincher came when a check with the Royal Greenwich Observatory disclosed that a huge sunspot, one of the largest ever recorded, was then crossing the solar meridian. Hey wrote a secret report within days. Although the report does not explicitly mention electromagnetic radiation directly from the Sun, Hey later concluded that the noise radiations were emitted by the Sun and finally, once wartime secrets subsided, published this fundamental result. (By this time, two other independent and later radio detections of the Sun, by George Southworth [1942] and **Grote Reber** [1943] had been published in the United States.) Studies of the Sun were to become the mainstay of radio astronomy for the next decade.

Hey's second major contribution also happened during the war, this time as a result of the 1944 V-1 and V-2 missile attacks on London. While developing improved radars to provide more warning time, many "false alarms" were noted from an altitude of ~100 km. This was a phenomenon called "short scatter," known from before the war and suspected to be of meteor origin, but with other possible origins, too. Immediately upon the end of World War II in Europe Hey organized simultaneous observations of these echoes from three different radar stations, and was able to demonstrate that they were caused by broadside reflections off the ionized trails generated by meteors as they entered the Earth's atmosphere. Furthermore, he identified two meteor showers, one already known (the δ Aquarids) and one of a type until then hidden from (visual) astronomers' ken, namely a shower with a *daytime* radiant. During August, Hey similarly studied the Perseid meteor shower. Thus began the field of meteor radar astronomy, which provided important new insights to astronomy over the following decade and which in particular was developed under **Bernard Lovell** at Jodrell Bank, University of Manchester.

As soon as the war ended, Hey's group also began mapping out, at a wavelength of 5 m, the extended Milky Way radiation studied before the war by the Americans **Karl Jansky** (the first person ever to do radio astronomy) and Reber. During the course of this survey (from Richmond Park, suburban London), Hey's colleague James W. Phillips noticed that the radiation from one particular sky position, a 2° region in the direction of Cygnus, fluctuated in intensity on time scales of 1 s to 1 min. They reasoned that these fast fluctuations implied that this region consisted of a large number of individual, discrete sources, rather than an extended medium, and that perhaps the sources were each like the Sun, which was also highly variable. This reasoning turned out to be flawed, and it took 5 more years of study by many groups before it was established that the variations were not intrinsic, but caused by the Earth's ionosphere. But Hey's group was correct in that the fluctuations could only occur because there was a compact source, called Cygnus A, and not broadly extended emission. The study of this source (which in 1951 was identified with a galaxy outside the Local Group) and many others that were soon discovered also became one of the central areas of radio astronomy.

Thus within a year of end of World War II Hey and his colleagues, working in a military environment and without the least bit of astronomical training, had made seminal contributions to both radar and radio astronomy. This came about basically from a combination of good equipment, a well-honed team with a "can-do" attitude stemming from the war, abundant support personnel, and a military hierarchy that, given AORG's excellent track record and the sudden lack of wartime exigencies, was willing to allow them considerable freedom. Moreover, Hey recognized and seized the opportunity to conduct "pure" research by retaining the best of his wartime team. Despite these successes, by the middle of 1947 radar and radio techniques were no longer being applied to astronomy at AORG. With the Cold War intensifying – for instance, the Berlin blockade began in April 1948 – such a line of pure research could no longer be justified. Hey turned his attention to more pressing military matters and did not contribute again to radio astronomy until, keen to resume research, he moved to the Royal Radar Establishment, Malvern, in 1952. His projects there included the role of induced currents in radar targets, the use of radar in meteorological research, and the effects of missiles on the upper atmosphere, modeled with an improvised Mach-15 shock tube.

The three radio astronomy groups, in Cambridge, Manchester, and Australia, whose establishment had been partly inspired by Hey's earlier discoveries, were all working at meter wavelengths. He was determined to push toward the centimeter regime. His first telescope operating at 10 cm was a captured German Wurzberg dish, with its diameter enlarged to 14 m, which was used to capture radar echoes from Sputnik and from the Moon. Hey's final achievement in radio astronomy was a two-element interferometer built on a kilometer-long track at an old airfield near Malvern in the early 1960s. He and colleagues R. L. Adgie and H. Gent thus became the first to measure radio source positions with the 1″ accuracy characteristic of optical astronomy.

Edna Hey suffered a severe stroke in 1986, and Stanley Hey, who had retired in 1969 to write books, spent most of the next 12 years caring for her. Characteristically, he became an expert on home health care, contributing articles on technical aspects of home nursing to *The Lancet* and receiving, at age 87, a grant from the Royal Society to further his research into developing pressure-support systems for bedridden patients. Hey received the Eddington Medal of the Royal Astronomical Society in 1959 and remained a member of the Commissions on Radio Astronomy and on Meteors of the International Astronomical Union until his death.

Woodruff T. Sullivan, III

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Hicetus

Flourished **possibly Syracuse, (Sicily, Italy), *circa* 400 BCE**

Almost nothing is known of Hicetus (or Nicetus) other than the fact that he was probably a Pythagorean. He is also thought to have lived in Syracuse. This knowledge comes to us from **Plutarch**, who calls him the ruler of the Leontines.

The Pythagorean school is known to have argued that the Earth rotates eastward on its axis. The interesting point about Hicetus is that he is sometimes credited with removing the Earth from the center of the Universe. **Nicolaus Copernicus** referenced Hicetus in his *De Revolutionibus* to show that even the ancient Greeks had considered this option.

Ian T. Durham

Alternate name

Nicetus

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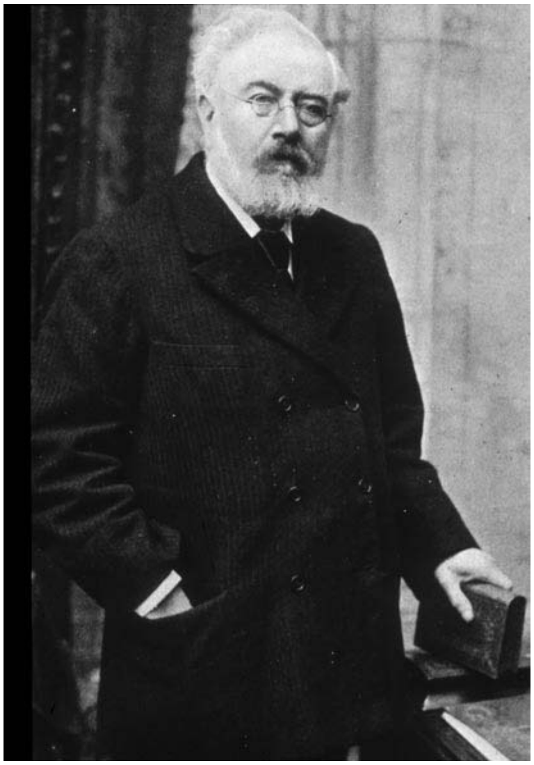
Higgs, George Daniel Sutton

Born **Clawton, Devon, England, 9 September 1841**
Died **Liverpool, England, 18 December 1914**



With a watchmaker's care Daniel Sutton raised to new heights the application of photography to the study of solar spectra.

Sutton was the fifth child of Samuel Sutton, an illiterate agricultural laborer, and his wife Elizabeth (*née* Cornish) Sutton. Sutton's father died when he was only 15 years old. At the age of 21, he married Mary Higgs, a domestic servant, at the Launceston Register Office. The couple later had two children.

At the time of his marriage, Sutton was described as a watchmaker, although no evidence survives as to his training. Yet, he must have acquired a good education that extended well beyond that provided by primary schools. Sutton was proficient in mathematics, natural philosophy (*i. e.*, physics), and chemistry, and understood Latin and French. Much of this knowledge might have been acquired from personal study, or from attendance at mechanics institute classes that were popular throughout mid-Victorian Britain.

Around 1865, during a move from Cornwall to Cumberland, Sutton changed his name to George Cornish Sutton Higgs. The reason for this change of name is not readily apparent. Higgs's wife died of tuberculosis in 1870, and George remarried in 1874 to Isabella Mylchrist Livesy. At this time, Higgs finalized his name, by usage, as George Daniel Sutton Higgs.

The Liverpool Trade Directories describe George Higgs as a watchmaker and jeweller, although he has also been referred to as an optician. It is more probable that he primarily assembled watches, as several watch movements and escapements are credited to Higgs's design in the family wills. Nonetheless, Higgs possessed considerable skills and knowledge of optics and constructed one of the finest solar spectrographs then in existence. The heart of this instrument was a concave grating of 10-ft. radius, figured by **John Brashear** of Pittsburgh, Pennsylvania, and ruled by **Henry Rowland** of Baltimore's Johns Hopkins University.

By the 1880s, Higgs was publishing papers on solar spectroscopy in the leading scientific journals. He was chiefly interested in photographically recording the Sun's spectrum at different solar elevations, and under various weather conditions, to investigate the effects of atmospheric absorption. He designed his own induction coil for producing comparison spectra and perfected methods of sensitizing photographic plates, using the bisulphite compounds of alizarine blue and coeruline to reduce exposure times. In Higgs's day, the red end of the spectrum was notoriously difficult to photograph, due to the relative insensitivity of plates to the longer wavelengths. After much experimentation, Higgs was able to obtain plates with all of the definition normally associated with the violet end of the spectrum. He also perfected methods of eliminating visible grain from the enlargements of his spectral photographs.

Higgs proposed to adopt Rowland's and **Anders Ångström**'s wavelength calibrations as the standard on which to work but felt that he could improve upon Rowland's spectral maps as they lacked information on changes due to variable atmospheric conditions. Higgs later entered into correspondence with **Alexander Herschel** in their attempts to refine the wavelength calibrations. Herschel championed Higgs's attempt to secure the directorship of the Liverpool Observatory, but this goal was not achieved.

During the 1890s, Higgs published two editions of his *Photographic Atlas of the Normal Solar Spectrum* and made a determination of the Sun's rotation period from spectroscopic observations. This latter attempt independently mirrored the work of American physicist Henry Crew. Higgs never formally published the solar rotation value but only remarked upon it in a lecture before the Liverpool Physical Society in December 1890. There, he showed that, by superimposing photographs of spectra taken from the eastern and western limbs, there was a slight displacement due to the Doppler effect, while the atmospheric absorption lines were unchanged. Some of these plates illustrated the first edition of Higgs's *Atlas*.

Higgs conducted his studies in a room of his small suburban house, using homemade apparatus. The accuracy of his line determinations and quality of his photographs were praised by leading British, Continental, and American astronomers and physicists. They regarded his work as comparable to or better than the results obtained from well-equipped observatories and university physics laboratories. American astronomer **George Hale** requested a visit to Higgs's laboratory, remarking that it was "so justly celebrated on account of your remarkable photographic work on the solar spectrum."

Recognition came during Higgs's lifetime with the award of several government grants, administered by the Royal Astronomical Society. Hale even tried (unsuccessfully) to secure $1,000 from the Carnegie Institution to support Higgs's researches. Higgs joined the Liverpool Astronomical Society in 1886 and was elected to its council in 1887. He was subsequently elected vice president of the society in 1893 and president in 1897. Higgs became a founding council member of the Liverpool Physical Society in 1889 and was elected a fellow of the Royal Astronomical Society in 1890.

Higgs occupies a small but honorable niche in late-Victorian science. He made no new discoveries and formulated no new theories to explain natural phenomena. Instead, he followed in the footsteps of others and refined their techniques with greater care and precision to produce one of the best atlases of the solar spectrum then produced.

Alan J. Bowden

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Hildegard of Bingen-am-Rhine

Born **Böckelheim, (Rheinland-Pfalz, Germany), 1098**
Died **Ruperstberg near Bingen, (Rheinland-Pfalz), 17 September 1179**

Abbess. Mystic. Saint? Hildegard the scholar wrote works of prose and music. Her cosmology exemplified the medieval role of the winds, which supported the cosmos and propelled the luminaries. Her drawing of the cosmos was, of course, earth-centered, but she showed a non-spherical shape shortly before **Thomas Aquinas** made spheres and circles cumpulsory for believers.

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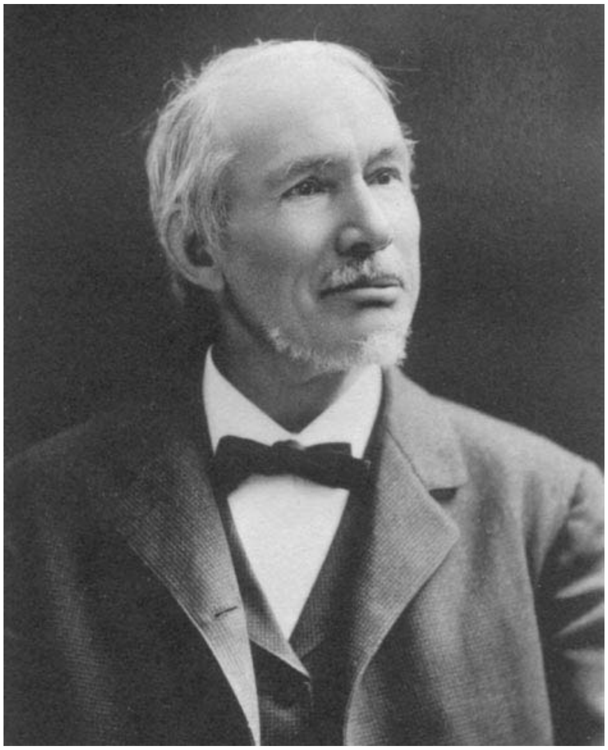
Hill, George William

Born **New York, New York, USA, 3 March 1838**
Died **West Nyack, New York, USA, 16 April 1914**

George Hill was one of the great masters of 19th-century mathematical astronomy. His parents, John William Hill and Catherine Smith, were farmers; both his father and grandfather were also artists. When Hill was about eight years old, his family moved to West Nyack, where he was to spend the majority of his life.

Hill attended Rutgers College (1855–1859), where he was deeply influenced by his mathematics teacher, Theodore Strong. From Strong's library, Hill borrowed classical texts in mathematical astronomy stretching back to the works of **Leonhard Euler**, many of whose



methods he seems to have absorbed. After receiving his degree, Hill pursued graduate studies in mathematics and astronomy at Harvard University, under **Benjamin Peirce**. In 1861, Hill was hired as an assistant by John D. Runkle of the United States Nautical Almanac Office (then located in Cambridge, Massachusetts). After about two years, however, Hill obtained permission to continue his work from the family's home in New York, where he remained until 1877. He never married.

Hill's first important works in celestial mechanics were developed there. He calculated the definitive orbit of Donati's comet (C/1858 L1) from 363 observations. He performed the calculations relating to the forthcoming transits of Venus that were witnessed in 1874 and 1882. But it was Hill's original contributions to lunar theory (regarding the complex motions of the Moon) that earned him the broadest recognition.

In Hill's day, lunar theory had been advanced along two fronts by **Peter Hansen** and **Charles Delaunay**, whose methods were somewhat opposed and yet complementary. Although Hill seems to have favored Delaunay's theoretical treatment (to which he one day hoped to return), he adopted Hansen's more pragmatic, computational approach, but with notable differences. In working to solve this three-body problem – the Moon's orbit around the Earth is notably effected by the gravitational pull of the Sun – Hill developed entirely new methods, including that of an infinite determinant, whose elegant solution yielded the mean motion of the Moon's perigee – a quantity that he calculated to fifteen significant figures. Hill's research into lunar theory was published in 1877, the same year in which he was called back to the Nautical Almanac Office (which had been relocated to Washington). As a consequence, Hill was never able to develop a more complete lunar theory along the lines of Delaunay; this task fell to his eventual successor at the Nautical Almanac Office, **Ernest Brown**.

When **Simon Newcomb** became director of the Nautical Almanac Office in 1877, he formulated the goal of recalculating the orbits of the planets to the highest precision. Jupiter and Saturn possessed the most complex motions; their mutual perturbations arose not only from their large masses but also because of the near-resonance between them – five Jovian orbits roughly equaled two Saturnian orbits. Newcomb entrusted the investigation of their orbits to no one but Hill, who reluctantly took up residence in Washington. Over the next fifteen years, he analyzed the positions and motions of these planets extending back to 1750. Although aided by one or more assistants, Hill performed the bulk of the calculations himself. He published his methods in volume 4 of the *Astronomical Papers Prepared for the Use of the American Ephemeris,* followed in 1895 by tables of the planetary motions. These tables remained in use until 1960. But as with the case of the Moon's orbit, Hill did not particularly advance the theories of the two planets' motions. His work in celestial mechanics was characterized not so much by elegant formulae as by the utmost precision in the determination of astronomical quantities. Newcomb's praise of Hill's achievements styled him "perhaps the greatest living master in the highest and most difficult field of astronomy, … [while] receiving the salary of a department clerk."

In 1892, Hill retired to his home in New York, and rarely left it except on special occasions. He was named an associate editor of the *Astronomical Journal* and elected president of the American Mathematical Society (1894–1896). Between 1898 and 1901, Hill delivered a course of lectures on celestial mechanics at Columbia University, but attracted only a handful of students, one of whom was **Frank Schlesinger**.

Hill received the Gold Medal of the Royal Astronomical Society (1887), the (Gold) Bruce Medal of the Astronomical Society of the Pacific (1909), and the Copley Medal of the Royal Society of London (1909). Named a member of the United States National Academy of Sciences and the Institute de France, Hill was awarded honorary doctorates by Cambridge University (1892), as well as by Columbia, Princeton, and Rutgers universities.

Four volumes of Hill's collected papers were published in 1905–1907 by the Carnegie Institution of Washington.

Steven J. Dick and *Jordan D. Marché, II*

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Hiltner, William Albert

Born **North Creek, Ohio, USA, 27 August 1914**
Died **Ann Arbor, Michigan, USA, 30 September 1991**

American photometrist William (Al) Hiltner codiscovered, with **John Hall,** the polarization of starlight caused by interstellar dust scattering. This, as interpreted by **Jesse Greenstein** and Leveritt Davis, Jr., was the observational discovery of the magnetic field of the interstellar medium, the third cosmic entity found to have one, after the Earth (**William Gilbert** 1600) and the Sun (**George Hale** 1908).

Hiltner was the son of John Nicholas and Ida Lavina (*née* Schafer) Hiltner. He attended very small country schools, developing an interest in astronomy apparently from an amateur living nearby. He received his degrees from the University of Toledo (BS 1937 in physics and mathematics) and the University of Michigan (MS 1938; Ph.D. 1942, in astrophysics).

Hiltner's thesis research concerned the spectra of Be stars and made use of a microphotometer he had constructed together with Robley Williams. The instrument incorporated an innovative mechanism to correct for the nonlinear relation between light received and density on a photographic plate, and was also used by them to construct a *Photometric Atlas of Stellar Spectra*.

In 1943, Hiltner was hired by **Otto Struve** to work at the University of Chicago's Yerkes Observatory. By 1946 Hiltner was supervising the construction of the Coudé spectrograph at the McDonald Observatory 82-in. telescope, and was also introducing the technique of photoelectric photometry at Yerkes Observatory, following the pioneering work by **Joel Stebbins** and **Albert Whitford** at the nearby Washburn Observatory of the University of Wisconsin.

At the suggestion of **Subrahmanyan Chandrasekhar**, Hiltner incorporated a polarizing analyzer into one of his photometers in order to search for the polarizing effect of electron scattering in the atmospheres of early-type stars. Hiltner studied eclipsing binaries where the asymmetry of the stellar disk during eclipse can give rise to a net linear polarization. To his surprise, a number of objects were found to exhibit stronger-than-expected polarization that was independent of the phase of the binary orbit. Hall's and Hiltner's papers on interstellar polarization appeared back-to-back in *Science* in 1949, and in retrospect, their map of polarization vectors in the sky can be seen as a map of the local magnetic field directions. Interpretation followed quickly, with Greenstein and Davis proposing one mechanism for aligning interstellar dust grains with a magnetic field and Thomas Gold proposing another; Gold's theory now seems to come closer to the truth.

Hiltner went on to develop more sensitive chopping polarimeters and to measure the polarization of more than 1,000 galactic stars as well as the Crab Nebula, radio sources such as Cass A and M87, and X-ray sources such as Sco X-1. He published many papers on eclipsing binaries, Wolf–Rayet stars, and optical counterparts to X-ray sources.

Broadly authoritative on instrumental matters, Hiltner worked on the development of electronographic cameras and photon-counting spectrometers. He edited the volume *Astronomical Techniques* in the influential compendium *Stars and Stellar Systems*, published in 1962.

Hiltner played a large role in the development of four major observatories. In 1946 he was made an assistant director of Yerkes Observatory, in charge of operations at McDonald. He served as director of Yerkes Observatory from 1963 to 1966. From 1959 to 1971, he was a member of the board of directors of Associated Universities for Research in Astronomy [AURA], and was influential in the establishment of the Cerro Tololo Interamerican Observatory [CTIO]. He served as an interim director of CTIO in 1966, prior to the appointment of Victor Blanco, and as president of AURA from 1968 to 1971.

Hiltner left Yerkes Observatory to become chairman of the Astronomy Department at the University of Michigan in 1970. There he established the Michigan–Dartmouth–Massachusetts Institute of Technology Observatory at Kitt Peak, first moving the 1.3-m telescope from Michigan to Arizona, and then constructing the 2.4-m telescope which bears his name.

In 1986 Hiltner accepted an appointment to the staff of the Carnegie Observatories in Pasadena, California; he was in charge of starting the Magellan Project. His efforts ultimately resulted in the construction of two 6.5-m telescopes at the Las Campanas Observatory in Chile. Hiltner retired from Carnegie Observatories in 1991 in order to have bypass surgery for a heart condition of long standing, and could not be revived following the operation.

Stephen Shectman

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Hind, John Russell

Born **Nottingham, England, 12 May 1823**
Died **Twickenham, Lincolnshire, England, 23 December 1895**

The son of a Nottingham lace manufacturer, John Hind's astronomical career began inauspiciously enough – he was hired at 16 as a supernumerary computer at the Royal Greenwich Observatory of **George Airy**. Airy was an early proponent of a factory model for his observatory; among other practices, he introduced a rigid timetable for his assistants' work, including the then novel practice of "clocking in," which promoted a severe disciplinary regime. **Edward Maunder**, a later assistant, recalled that under Airy's "remorseless sweating," assistants did not typically survive past the age of 46.

Hind was and remained an efficient computer and survived in this grinding role for several years. He also served as an assistant in the Magnetic Department of the Royal Observatory, and participated in the Government Chronometer Expedition to determine the longitude of Valentia, Ireland. In June 1844, he escaped to a position at George Bishop's private observatory, South Villa Observatory, at Regent's Park. Bishop was a wine-maker and retailer whose products were said to account for half the British wine excise, and in his mid-40s, by which time he had amassed a large enough fortune to do whatever he liked, Bishop devoted himself to scientific interests. At 50, he worked his way through **Pierre de Laplace**'s *Mécanique céleste*. He also acquired a 7-in. Dollond refractor and hired a series of gifted but unaffluent astronomers who observed with it in his name. Bishop was obviously a very good judge of talent. Before Hind acceded to the position, the observatory had been used by **William R. Dawes** – "eagle-eyed" Dawes – to observe double stars from 1839 to 1844. Dawes was followed by Hind, and among Bishop's later assistants were **Norman Pogson**, **Albert Marth**, Eduard Vogel, and C. G. Talmadge.

In 1845, Hind was inspired by the discovery, by Dresden post master **Karl Hencke**, of a new "planet"– a minor planet, as we should say today – (5) Astraea. Hind and Airy were, in fact, the first two British astronomers informed of Hencke's discovery by continental astronomers. Hind observed it carefully from London and computed its position, which he sent to Airy and others.

In early September 1846, Hind got wind, apparently from Dawes, who in turn had been informed by Sir **John Herschel**, of another planet search that had been unfolding secretly at the Cambridge University Observatory under the direction of **James Challis**. Hind hoped to join the effort himself, but all of these British efforts were forestalled when the planet Neptune was discovered by **Johann Galle** at Berlin on the basis of **Urbain le Verrier**'s calculations. In the event, Hind received the first word of its discovery from Berlin on 30 September and was the first to knowingly observe the planet from Britain. "What a grand discovery this is, and how glorious a triumph for analysis!" he wrote to **John Adams**. Eventually, Adams was granted a share in the triumph with Le Verrier when his own preliminary calculations predicting the position of the planet came to light. Interestingly – and it is a testament to Hind's prestige among the British astronomers at the time – Hind was Adams's most regular correspondent in the period leading up to the discovery of Neptune, though this correspondence concerned comets not planets! Given Hind's later success as a discoverer of asteroids, it is likely that if he had been foremost rather than hindmost among British searchers, the discovery would have been made in London rather than Berlin.

Hind, as a non-Cantabrigian, was one of the most vocal critics of the "inexcusable secrecy" with which the search had been carried out in Britain. Airy, Challis, and Adams were all Cambridge graduates. Hind also ridiculed the attempt, by Challis and Adams, to promote their name ("Oceanus") for the planet in competition with the French proposals of "Neptune" or "Le Verrier." "It appears to me very intrusive in the Cambridge people," he wrote to Reverend **Robert Sheepshanks**, "to urge a name for the planet ... and one too which is no more likely to succeed with the French (who have the only right to name it) than if it had been dubbed 'Wellington.'" Hind participated in post-discovery efforts, led by **William Lassell**, to establish the existence of a satellite and even a ring around the new planet. Although the moon was confirmed, the ring proved to be illusory. We now know that Neptune does have rings, but they would not have been visible in the instruments used by observers of the 19th century.

The year 1847, after the discovery of Neptune, was Hind's banner-year. He added luster to the reputation of Bishop's observatory as the discoverer of a comet and two minor planets, (7) Iris and (8) Flora. Because of the controversy surrounding the discovery of Neptune, the Gold Medal Committee of the Royal Astronomical Society [RAS] was unable to agree on a recipient of its medal, and instead bestowed testimonial letters on the 12 people who had been nominated to receive the medal, including Herschel for his Southern Hemisphere research, **Peter Hansen** for his work on the motions of the Moon, Hencke and Hind for their asteroid discoveries, and Adams, Airy, and Le Verrier for the Neptune discovery.

Hind's next asteroid discovery, the 12th overall, took place on 13 September 1850, during the year of Queen Victoria's jubilee. Hind called it (12)Victoria, a choice opposed by the American editor of the *Astronomical Journal*, **Benjamin Gould**, who insisted in accordance with the rules in force at the time that all names had to be chosen from those of the divinities of classical mythology. (This was before the discovery of asteroids ran rampant!) Yet the debate quieted when another American, Harvard College Observatory director **William Bond**, pointed out that Victoria had been, after all, a minor Roman divinity. In all, Hind discovered 10 asteroids – the last in 1854. In 1853 he was awarded the Gold Medal of the Royal Astronomical Society.

In 1853, Hind was appointed superintendent of the Nautical Almanac Office, a position which he received in preference to Adams and which he held until his retirement in 1891. The South Villa Observatory was closed in 1853; Bishop and Hind moved to Twickenham, where Bishop set up a new observatory. Bishop and Hind observed the Leonid meteors from Twickenham in 1866. When the observatory at Twickenham was finally closed in 1877, the instruments, including the Dollond refractor, were given to the Royal Observatory at Naples.

Hind is perhaps best remembered today by his discovery, on 11 October 1852, of the nebulous object T Tauri; it was later found to be of variable brightness (Hind's variable nebula, NGC 1555), and is now regarded as the prototype of the T Tauri variable stars. Hind also discovered the galaxy NGC 4125 in Draco (1850), and the globular clusters NGC 6535 in Serpens (1852) and NGC 6760 in Aquila (1845). Among Hind's other notable discoveries were the variable star R Leporis (Hind's crimson star), which he found in October 1847, Nova Ophiuchi (1848), and the dwarf nova U Geminorum (1855). In addition to the RAS Gold Medal, Hind was the recipient of many other medals and honors, including the Royal Society's Gold Medal, a gold medal from the King of Denmark, and the Lalande Medal on six separate occasions from the French Academy of Sciences. He was awarded an honorary LLD from the University of Glasgow.

Hind was married in 1846 and had six children.

William Sheehan

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Hinks, Arthur Robert

Born **London, England, 26 May 1873**
Died **Royston, Hertfordshire, England, 18 April 1945**

Arthur Hinks achieved recognition for his work in geography, photographic astrometry, and the determination of the solar parallax. He received his training at the Whitgift Grammar School in Croydon and at Trinity College, Cambridge, where he was a senior optime in part I of the mathematical *tripos*. After obtaining his degree in 1895, Hinks was appointed second assistant in the Cambridge Observatory, and from 1903 to 1913 served as the chief assistant under Sir **Robert Ball**. In the fall of 1903, the young **Henry Norris Russell** came to Cambridge and worked closely with Hinks during the next few years. Russell was not only a valued colleague, but also a moderating influence on the volatile Hinks, who was prone to engagement in heated debates on the floor of the Royal Astronomical Society sessions.

Hinks had the unfortunate luck to be eclipsed at Cambridge by Sir **Arthur Eddington**. Eddington moved from Greenwich to Cambridge to succeed **George Darwin** as the Plumian Professor of Astronomy and Experimental Philosophy, and he was further granted the directorship of the Cambridge Observatory upon Ball's death in 1913. Hinks left the observatory in 1913 to become the assistant to, and subsequently, the secretary of, the Royal Geographical Society. He held the latter position until his death. Although Hinks's duties in conducting the business of a great learned society placed heavy demands upon his time, he maintained his interests in astronomy, and lectured yearly on the subject through 1941.

Hinks was the recipient of numerous awards both in astronomy and in geography. He was elected to the Royal Society, and was awarded the Gold Medal of the Royal Astronomical Society in 1912. In recognition of his contributions to the preparation of military maps for World War I, Hinks was made a Commander of the Order of the British Empire in 1920. He received the Victoria Medal of the Royal Geographical Society (1938), and the Cullum Medal of the American Geographical Society (1942).

Hinks's major astronomical contributions centered on the development of photographic astrometry. By the end of 1898, the Sheepshanks photovisual telescope was completed. Much of the supervision of its erection and adjustment fell to Hinks, who subsequently made efficient use of this novel telescope for the determination of the solar and stellar parallaxes. In the course of this work, it was necessary for him to undertake a careful and detailed study of the sources of error in the measurement of parallaxes from photographic plates. This work brought Hinks and Russell in conflict with others, who were reticent to accept the use of photovisual methods in determining parallaxes.

The 1898 discovery of the asteroid (433) Eros opened the possibility for a precise measurement of the solar parallax. Hinks obtained 500 exposures of Eros during the opposition of 1900/1901, and continued to work on the problem throughout the remainder of his tenure at the Cambridge Observatory. His photographs revealed that the visual magnitude of Eros fluctuated with a period of 2 hours and 38 min, pointing to an irregular shape to the object. The principal result of Hinks's work was the painstaking determination of the solar parallax as 8.807 ± 0.0027 seconds of arc (versus the presently accepted value of 8.794).

Thomas J. Bogdan

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Hiorter, Olof

Born **1696**
Died **1750**

Olof Hiorter and fellow Swede **Anders Celsius** correlated the appearance of aurorae with changes in the behavior of the Earth's magnetic field.

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Hipparchus of Nicaea

Born **Nicaea, (Iznik, Turkey), *circa* 190 BCE**
Died **possibly Rhodes, (Greece), *circa* 120 BCE**

Hipparchus is remembered chiefly for compiling a star catalog; measuring and attempting to explain what **Nicolaus Copernicus** later named "precession of the equinoxes," developing usefully predictive models for solar and lunar motions, and determining distances to the Sun and Moon. He compiled the first trigonometric table (giving the chord function) and may well have invented trigonometry. Hipparchus introduced 360° angle measure and sexagesimal arithmetic from Babylon, invented a stellar magnitude scale that we still use (in updated form) today, and possibly invented the planar astrolabe. He applied astronomy to geography, particularly the use of gnomons for determining terrestrial latitudes. Hipparchus's most important influence, though, was to move Greek astronomy away from idealistic, theoretical, and qualitative geometry, toward precise, predictive, and empirically confirmed computation.

Hipparchus "of Rhodes," as some moderns call him, was actually from Nicaea, the capital of Bithynia. Of Hipparchus's life and parentage, we know practically nothing. And though he is widely deemed the greatest of Greek astronomers, we know but little about his work – ancient writers credit Hipparchus with a dozen distinguishable works in astronomy, but only his *Commentary on the Phenomena of Aratus and Eudoxus* survives intact. This commentary belongs to a long-standing discursive tradition concerned with constellations and astrological weather forecasting. In its third and final book, we find Hipparchus's own description of the constellations, plus the positions of 44 bright stars that he determined for telling time by night. Some of Hipparchus's later measurements are preserved in **Ptolemy**'s *Almagest,* which is also our main source of information about Hipparchus's mathematical astronomy.

Hipparchus's observations span the years 147–127 BCE and, though the evidence is not irrefutable, are thought to have been taken from Rhodes. The resulting star catalog was almost certainly not a systematic table of coordinates, but a mixture of notations – lists of stars that are collinear, distances between stars, and declinations. This odd mix facilitated Hipparchus's interest in detecting changes in the heavens. **Pliny** explains that Hipparchus noticed a "new star" that moved "in its line of radiance." Hipparchus thus wondered whether the fixed stars really are fixed. He therefore began to measure their positions and magnitudes with that question in mind. As for Hipparchus's new star, it remains mysterious. Some identify it with a comet in 134 BCE (that returned in 120 BCE); others with a nova in the Chinese records for 134 BCE. The new star is not documented in the remains of Hipparchus's catalog, but we do find two "cloudy" stars: the Praesepe Cluster M44 (previously recorded by **Aratus**), and the Double Clusters h and χ Persei.

Precession of the equinoxes came to the fore while Hipparchus investigated the constancy of the year, by timing successive equinoxes. These data, even when combined with those of **Timocharis** and **Aristyllus** a century earlier, were recorded only to the nearest quarter day, and proved insufficiently precise and spanned too short a time to yield a worthwhile estimate for the year. So Hipparchus worked instead from Babylonian data, concluding 365+1/4+1/144 days for the sidereal year, and 365+1/4–1/300 days for the tropical year, well within what the limited range of observations could confirm. The difference between the sidereal and tropical years indicates equinoctial drift against the ecliptic of "no less than 1° per century," as Ptolemy put it. Though Hipparchus is commonly said to have *explained* this by adding a precessional motion to the sphere of fixed stars, that credit actually belongs to Ptolemy's Islamic successors. Hipparchus himself seems undecided on what was happening, which is understandable given his apparent awareness of the limits inherent in the data available to him. He tentatively suggested that both equinoctial shift and mutation of the constellations occurred because stars near the ecliptic moved at a rate different from those near the poles.

Hipparchus accounted for the different lengths of seasons (as defined by the equinoxes and solstices) and annual variations in the apparent solar speed by assigning the Sun to a uniform circular orbit centered away from the Earth. Finding the center of this orbit involved trigonometry, perhaps motivating the construction of his chord table – for without a tabulated trigonometric function, one must resort to first principles. The most important astronomical advance here is in Hipparchus's approach: for the first time, a Greek geometrical model has been fitted to precise observational data. The same is seen in Hipparchus's model of the Moon – he took the deferent-epicycle construction invented by **Apollonius**, and massaged it to fit Babylonian data for the sidereal, anomalistic, and draconitic periods. The lunar model is accurate only when the Moon is near opposition and conjunction, as Hipparchus knew. But because eclipse prediction was his goal, these are precisely the times when accuracy was most needed.

Hipparchus's interest in eclipses led him also to determine the relative sizes and distances of the Sun and the Moon, using parameters from the long-established Babylonian observational tradition. But Hipparchus did not simply take the Babylonian parameters for granted – as a check, he computed from them a *new* eclipse period, which he then compared against available data from the several preceding centuries. Only a few suitable eclipse pairs could be fished from the records, but they agreed well enough to confirm the Babylonian parameters. Hipparchus's appreciation for the limits of observational data is evident also in his calculated distance to the Moon – he gives only a lower bound, computed by assuming that the Sun is at infinity, and an upper bound, limited by the precision with which he could measure solar parallax.

According to Ptolemy, Hipparchus failed to produce models for the motions of the other celestial bodies, though he did successfully refute earlier models. But clearly, Hipparchus's attempts provided the foundations for Ptolemy's own work, and hence for all mathematical astronomy up to the Copernican period.

On the cosmological front, Hipparchus's epicycles and eccentric orbits spawned trouble – although observations *confirmed* the calculations, physics could not *explain* them. The absence of a suitable physics remained problematic well into the 17th century, since cosmologists naturally wanted to know *why* heavenly bodies would move along such oddly compounded circular orbits. Hipparchus did produce some physics of his own – **Philoponus** and **Galileo Galilei** later wielded Hipparchus's theory of projectile motion against **Aristotle**, and Hipparchus also seems to have written on how the celestial realm influences the terrestrial – but neither his nor any other physics ever succeeded in making the compounded off-center circles convincingly real. They were widely deemed a mere calculators' convenience. Mere convenience or not, Hipparchus sired an astronomy that was computational, predictive, and empirical, and which thrived well into the dawn of modernity.

Alistair Kwan

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Pliny the Elder (1938). *Natural History*, translated by H. Rackham. Loeb Classical Library, no. 330. Cambridge, Massachusetts: Harvard University Press. (Pliny tells the story of Hipparchus's star catalog in Book II Chap. 24, where he also lauds Hipparchus for work on the astrological influence on humans, and for showing that "our souls are part of heaven." Hipparchus's work on eclipses is mentioned in a brief but difficult passage in Book II Chap. 9 [with further material in Chap. 10], on which see the article by Goldstein and Bowen. At Chap. 79, Hipparchus is said to have defined the day as the time between two successive midnights; at Chap. 112, he is said to have added 26,000 stades to the circumference of the Earth as calculated by Eratosthenes.)

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Hippocrates of Chios

Born **Chios (Khíos, Greece), *circa* 470 BCE**
Died **Athens, (Greece), *circa* 410 BCE**

Hippocrates was a Greek geometer and astronomer whose works are known only through references by later authors.

Hippocrates was born on the island of Chios, off the west coast of what is now Turkey, and spent most of his adult life in Athens, where he journeyed to prosecute pirates who had stolen his property. In that city, Hippocrates attended lectures and attained significant proficiency in geometry. More than one author (*e. g.*, **Eudemus** and **Theophrastus**) maintained that he was not a practical man, but that he excelled in geometry.

Hippocrates's was the first known work on the elements of geometry, preceding Euclid's *Elements* by about a century. He made significant discoveries in two of the three most important geometrical problems of ancient times, duplication of the cube and squaring the circle. He is not known to have addressed the third problem, trisection of the angle, at least in works that cite him. These are all "impossible" problems because they cannot be solved using only an unmarked straight edge and a compass.

An important motivation for Greek studies of geometrical constructions was their application to astronomy – for example, measurement of the sizes of the Earth, Moon, and Sun. Hippocrates discovered crescent-shaped figures – lunes or lunules – whose area can be squared, unlike the circle, whose area cannot be squared without resorting to nongeometrical methods. Hippocrates is also credited with inventing the method of geometric reduction, the passage from one problem to another whose solution depends on the solution of the former.

Aristotle mentions Hippocrates of Chios among the Pythagoreans to dispute their view that comets are like planets but seen rarely, as Mercury is seen rarely because it rises only a little above the horizon. They believed that a comet's tail does not belong to the comet itself but is "assumed by it on its course in certain situations when our sight is reflected by the Sun from the moisture attracted by the comet. It appears at greater intervals than the other stars because it is slowest to get clear of the Sun and has been left behind by the Sun to the extent of the whole of its circle before it reappears at the same point."

Aristotle mentions the Pythagoreans in his discussion of the Milky Way, which he says they believe was either a path caused by a star that fell from heaven or by the Sun scorching the circle (of the Milky Way) when it moved in that region, and that **Anaxagoras** and **Democritus** say it is the light of certain stars. Hippocrates is also mentioned by **Eudemus of Rhodes**.

Thus we can conclude that Hippocrates was among those early observers of celestial phenomena who struggled with many different causative models to explain what they saw. His work in geometry tied in with the observational material gathered and discussed by the Pythagoreans. **Hipparchus** and **Ptolemy** were his worthy descendents, creating what we know of Greek mathematical astronomy. Hippocrates was one of those Greeks who made the beginnings of science possible, believing that natural phenomena were not ruled by inscrutable gods but that they could be understood by careful observation and analysis.

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Hirayama, Kiyotsugu

Born **Sendai, Japan, 13 October 1874**
Died **probably Tokyo, Japan, 8 April 1943**

Kiyotsugu Hirayama, who contributed to celestial mechanics and the theory of variable stars, is best remembered for the identification of asteroid families, based on their orbital characteristics.

Hirayama was the only son of a naval architect. In 1897, he completed the course on astronomy at the Tokyo Imperial University. In 1906, he was appointed assistant professor of astronomy at the Tokyo Imperial University, and in 1919 was promoted to professor. By the time Hirayama left the university in 1935, he had taught every course in classical astronomy and was engaged in constructing Japanese nautical almanacs at the Tokyo Astronomical Observatory. In the period 1919–1928 both of the two professors of astronomy were a Hirayama. (The other was Shin Hirayama (1868–1945), who was the second director of the Tokyo Astronomical Observatory in 1920–1928 and a vice president of the International Astronomical Union [IAU] in 1922–1928.)

Early in his scientific career, Kiyotsugu Hirayama made latitude observations and studied latitude variations; he was awarded a doctorate in 1911 on this subject. During 1905–1907, he was a member of the committee for determining a 50° latitude border in Sakhalin after the Japanese –Russian war and made latitude observations there. After this duty, Hirayama was awarded the Saint Anna's Decoration from the Russian government.

In 1916, Hirayama was sent to the United States by the Japanese government and stayed at the Naval Observatory in Washington to work on nautical almanacs. Then he moved to Yale University to develop lunar theory with **Ernest Brown**, who advised him to study motions of minor planets. During his stay at Yale, Hirayama published "Groups of Asteroids Probably of Common Origin" in the *Astronomical Journal* (1918). In it, he computed secular perturbations for each minor planet to derive proper eccentricity and inclination, which are stable quantities. By using these two quantities as well as the semi-major axis, which is stable in the secular perturbation theory, he could identify several groups of minor planets that have similar values of the three parameters. These groups are called families. Hirayama believed that the minor planets belonging to any family had the same origin, namely, that they were created from one or two minor planets by collision.

After he came back to Japan, Hirayama continued this work and published a more complete paper in the *Japanese Journal of Astronomy and Geophysics* in 1922. When Hirayama published his papers, the number of minor planets was only around 1,000, but he discovered almost all of the major families that are now known. Hirayama's papers are still quoted when origins of small bodies in the Solar System are discussed.

In 1935, Hirayama was elected a member of the Japan Imperial Academy. However, he was never awarded any prize for his work. He was a delegate to the IAU General Assembly in 1925 (Cambridge, England) and 1932 (Cambridge, USA).

As he learned Chinese classics in his early years of school, Hirayama could read Chinese literature easily and knew much about the history of Chinese astronomy. He was survived by his wife, a son, and two daughters. His other son had died a year earlier.

Yoshihide Kozai

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Hire, Philippe de la

Born **Paris, France, 1640**
Died **Paris, France, 21 April 1718**

Philippe de la Hire was a mathematician, an observational astronomer, and a key figure in the Académie royale des sciences. La Hire was the eldest child of Laurent de la Hire, *peintre ordinaire du roi* and professor at the Académie royale de peinture, and Marguerite Coquin. Laurent was a well-known artist whose patrons included Cardinal Richelieu. Laurent and his wife were well off financially – they owned several properties in Paris – and their residence was frequented by leading figures from the worlds of the visual arts and the mathematical sciences. The geometer Gérard Desargues was one of Laurent's closest friends. Laurent intended Philippe also to be a painter, and to that end educated him personally. Philippe's study of geometry was assisted by Desargues, who probably introduced him to projective geometry. Laurent, who admired the Venetian masters, urged Philippe to go to Venice, which he did in 1660, remaining there for 4 years. He also worked on classical geometry, especially the *Conic sections* of **Apollonius**.

After his return, this young man of independent means devoted himself to projective geometry, drawing, and painting. He collaborated with the engraver and geometer Abraham Brosse, who also had worked with Desargues. In 1672 La Hire published his *Observations … sur les points d'attouchement de trois lignes droites qui touchent la section d'un cone …*. This was followed in 1673 by his *Nouvelle méthode en géométrie pour les sections des superficies coniques et cylindriques*. The *Nouvelle méthode* displays the influence of Desargues, yet La Hire denied that he knew Desargues's work on conics before 1672, only encountering it later. It is an early example of La Hire's propensity to claim that his publications owed little to others.

By the time he published the *Nouvelle méthode,* La Hire's personal circumstances had changed. In 1670 he married Cathérine le Sage, who came from a Parisian bourgeois family. They had four children by the time she died in 1681. Later that year he remarried, his second wife being Cathérine Nonnet, the daughter of a notary; four more children were born of this marriage. In 1679 La Hire published his *Nouveaux élémens des sections coniques …*, and in 1685 his most comprehensive treatise on conic sections, *Sectiones conicae in novem libros distributatae*.

La Hire had attracted the attention of the Académie des sciences and in 1678 was brought in as an astronomer, despite lack of astronomical experience. It is unclear as to who suggested to J. B. Colbert, protector of the academy, that he be appointed. **Jean Picard** may have been involved, for La Hire's first task was to assist him with surveys for the new atlas of France, which the academy was preparing. In 1679 La Hire accompanied Picard to Brittany and in 1680 to Guyenne. They then split up, La Hire concentrating on Calais and Dunkirk (1681) and Provence (1682). In this latter year Picard died. Philippe inherited his scientific instruments and papers. La Hire and his family also moved into the Paris Observatory, which became their permanent residence.

Astronomy never monopolized La Hire's attention. In 1683 **Jean Cassini** began to extend the meridian line that Picard had begun, and he placed La Hire in charge of the project to the north of Paris. From 1684 to 1685 La Hire worked on the scheme to provide a water supply for Versailles. He continued his studies in geometry, and developed interests in optometry, mechanics, and meteorology. La Hire held two teaching posts: In 1682 he was made professor of mathematics at the Collège Royal and in 1687 became professor at the Académie d'Architecture. He accepted editorial duties, seeing through the press works by Picard and Edme Mariotte. La Hire was fascinated by scientific instruments and conducted experiments on clocks, thermometers, and barometers.

La Hire acquired a mastery of the instruments at the observatory – a new quadrant in the plane of the meridian was installed in 1683 – and developed his observational skills. He had received instruction from Picard, but in Cassini, who also resided at the observatory, he had another first-class guide.

La Hire acquired a good grounding in astronomical theory, but concluded that it rested on unsure foundations: The tables with which astronomers worked, including the Rudolfine Tables of **Johannes Kepler**, contained so many inaccuracies that even the most sophisticated theory was rendered unsound. The principal challenge facing astronomers was, in La Hire's opinion, to improve the quality of observation. This required progress on two fronts: superior observational instruments and more accurate clocks, hence his own experiments with clocks and his design, for example, of new types of reticules for observing eclipses.

La Hire concentrated on observing planetary and stellar motions, eclipses of the Sun and Moon, sunspots, planetary conjunctions, and the passage of comets. The more he observed, the more he became convinced that irregularities in the movement of celestial bodies were so frequent that no theory could do more than approximate to physical reality. He published two main sets of astronomical tables: *Tabularum astronomicarum* … (1687) and the more comprehensive *Tabulae astronomicae Ludovici Magni* … (1702; reprinted 1727, French translation 1735). The latter appeared just as the War of the Spanish Succession was beginning, and the reference to Louis XIV implied that, just as La Hire's tables surpassed those of Kepler, so did the King of France outshine the Holy Roman Emperor.

Responses to the *Tabularum astronomicarum* were mixed. **John Flamsteed**, for one, was disappointed that it referred only to 63 stars, and contained errors in the declination of some stars. However the *Tabulae astronomicae* proved more controversial. It contained a preface in which La Hire justified the conduct of observations as the chief duty of the astronomer. He referred to improvements to instruments that personally he had made, and later in the book included passages instructing the reader in observational techniques. **Bernard de Fontenelle**, secretary of the academy, included a notice of the *Tabulae astronomicae* in the *Histoire et Mémoires de l'Académie Royale des Sciences* for 1702.

However, behind this apparently successful publication lay a more discordant reality. Among La Hire's papers are two statements by Cassini and his assistant **Giovanni Maraldi** in which they level certain charges against him. First, he did not submit his manuscript to the academy for approval (an obligation all the more necessary since La Hire associated the observatory with his observations); perhaps he was afraid that, had he done so, substantial corrections might have been proposed. Second, although Cassini and Maraldi worked with him at the observatory, he had neither informed them of his intention to publish the tables, nor consulted them about the contents. Third, he greatly exaggerated his role in refining the instruments at the observatory, while understating the contributions of his colleagues. Fourth, his text implied that all the observations in the *Tabulae astronomicae* were his own, whereas many were by others. The formal records of the academy are silent on this dispute, but relations between La Hire and Cassini thereafter were strained.

This was not the only quarrel involving La Hire. In 1694, his son Gabriel-Philippe had joined the academy. Gabriel-Philippe's first individual publication was the *Ephémérides* for 1701, in which he reproached a fellow academician, **Jean le Fèbvre**, for making a serious mistake in an observation made on 15 March 1699. Gabriel-Philippe did not name Le Fèbvre, but everybody knew to whom he referred. Le Fèbvre edited the journal *Connaissance des Temps*, and in the edition for 1701 accused Gabriel-Philippe and his father – again, neither was named, but their identity was unmistakable – with lies, plagiarism, and the falsification of observational data. The affair blew up in the academy. Le Fèbvre was required publicly to apologize and to reissue the *Connaissance* with the offending passage removed. He was spared the public apology, but ceased attending the academy, from which he was expelled in 1702. He also lost the editorship of the *Connaissance des Temps*.

After the controversies of 1701 and 1702, La Hire concentrated on his observations and other scientific activities, and continued publishing accounts of eclipses, sunspots, and other celestial phenomena. At the time of his death, he was a senior member of the academy, and had seen his younger son, Jean-Nicolas, also become a member (1710). La Hire's career illustrates the tensions and controversies that could attend the practice of astronomy in the Académie des sciences, and exemplifies the multifarious pursuits in which many scientists engaged in this period.

David J. Sturdy

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Hirst, George Denton

Born **Sydney, New South Wales, (Australia), 7 April 1846**
Died **Sydney, New South Wales, Australia, 20 May 1915**

George Hirst prepared colored drawings of Jupiter and Mars that were considered equal to those of **Nathaniel Green** in both the beauty and the accuracy of their rendering. A partner in the business of Tucker & Company, wine and spirit merchants, Hirst was the son of George R. and Caroline L. Hirst. As a prominent amateur in Sydney scientific circles, Hirst was active in both astronomy and microscopy, but it is as an amateur astronomer that he is best remembered. In 1874, as a skilled astronomical observer he participated in the work of the temporary observatory at Woodford, one of four set up in New South Wales to supplement the Sydney Observatory's observations of the transit of Venus.

In the late 1870s Hirst's drawings of Mars and Jupiter attracted particular notice. His obituarist in the Royal Astronomical Society [RAS] *Monthly Notices* considered that Hirst had no equal in Australia as an astronomical draughtsman, and that his "drawings of Mars were marked by the same skill and delicacy as those of N.E. Green of England." Hirst was also an observer of double stars; his measurements were published in the *Monthly Notices of the Royal Astronomical Society* and in the Journal of the British Astronomical Association.

In addition to his own observations Hirst provided advice and guidance to fellow amateurs in an informal way and served as president of the New South Wales Branch of the British Astronomical Association. When the Royal Society of New South Wales made provision for specialist sections in 1876, Section A encompassed "Astronomy, Meteorology, Physics, Mathematics and Mechanics." The most prominent members of Section A included government astronomer **Henry C. Russell**, **John Tebbutt**, **Robert Innes**, and Walter Frederick Gale (1865–1945), so in practice Section A was largely devoted to astronomy. Hirst was an active participant for most of its brief existence, serving as secretary for 2 years. He was elected a fellow of the RAS in London in 1895, and was active in astronomy for some 40 years.

Hirst also served variously as president of the Royal Society of New South Wales (which he joined in 1876) and chairman of its microscopical section. As a member of the microscopical section in the early 1880s, Hirst took a particular interest in the new immersion objectives becoming available.

Hirst lived for the last 20 years of his life in the Sydney suburb of Mosman where he was able to indulge his other avocational interest, that of yachting. He was a close friend of and lived not far from the home and private observatory of William John MacDonnell (1842–1910) who served variously as president, secretary, and treasurer of the New South Wales Branch of the British Astronomical Association. Hirst died at his home after some months of indifferent health. The New South Wales government astronomer professor W. E. Cooke was among the mourners at his funeral. Hirst was survived by his wife Mary (*née* Rose) whom he had married in 1888, and a son and a daughter.

Julian Holland

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Hirzgarter, Matthias

Born **Maschwanden, Zürich Canton, Switzerland, 28 November 1574**
Died **Zürich, Switzerland, 9 February 1653**

Matthias Hirzgarter's writings made early telescopic observations available in German for the first time, and therefore accessible to a larger reading public. Hirzgarter grew up in a traditional clergyman's family in the countryside, attended first the local school and then the University of Zürich. After touring Denmark and Scotland, he found his first position as a schoolmaster in Kloten, but from 1612 on, he was a pastor in Zollikon. In addition, Hirzgarter was also involved in medicine and composed an almanac that has not been preserved. Several times he came into conflict with envious officials from the Zwinglianist church and, in 1637, left his position in the church.

Hirzgarter had been engaged in astronomy for many years. His earliest preserved writing, *Epilogismus duarum Lunae eclipsivm*, is devoted to the two lunar eclipses in 1635. He calculated the eclipses according to **Philip Lansbergen**'s tables and presented in detail all the astronomical and mathematical data, along with all the steps involved in the calculation. Hirzgarter's *Astronomia Lansbergiana* (1639) dealt with the computation of solar eclipses in general and the one on 22 May 1639 in particular. The calculations were based on the principles of the Copernican system and on David Organus' ephemerides.

In his 1643 work, *Detectio Dioptrica, Corporum Planetarum Verorum*, Hirzgarter presented early telescopic observations of the planets, the Sun, and the Moon, some of which were his own and some taken from the work of other astronomers, such as those of **Francesco Fontana**. It is not known if he built his own telescope or in which location he might have used it. Observations with the telescope were seen by Hirzgarter to be important because they helped to correct astronomy and free it from superfluous hypotheses. He described discoveries about the Sun, Moon, and all the planets made by means of the telescope. Concerning the Moon, he emphasized the extensive system of rays and the generally rough and mountainous surface that is especially visible on the edge of the terminator. On Mercury and Venus, he was himself able to perceive patterns of light. Saturn, Hirzgarter writes, viewed with poor telescopes appears to be an "olive," but good telescopes reveal two half rings or arms that give the planet a "monstrous appearance." It is especially Mars that shows, with its movements, that the system of **Nicolaus Copernicus** corresponds to the true structure of the Universe because that planet can appear both above and below the Sun (whose form he was unable to detect with the telescope but which he remarkably imagined in the shape of a mountain). Jupiter, with its four satellites, constitutes a special world. Using a colored glass, spots could be observed on the Sun, and they indicated that it moves around its own axis. The stars, given their various diameters, are located at various distances and not in the same general sphere.

Jürgen Hamel

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Hoek, Martinus

Born **The Hague, the Netherlands, 13 December 1834**
Died **Utrecht, the Netherlands, 4 September 1873**

Martin Hoek researched the trajectories of meteors, minor planets, and comets in particular. He began his studies at Leiden in medicine in 1852, before turning to mathematics and astronomy there in 1854. After earning his Ph.D. in 1857, he became professor of astronomy at Utrecht University in 1859. Hoek provided reports on minor planets in the *Astronomische Nachrichten* from 1857 to 1866. In 1865, he first drew attention to the existence of "comet families." After the Parisian comet scare of 1857, he showed that the comets of 1264 (C/1264 N1) and 1556 (C/1556 D1) were in fact not the same, and thus there had not been any danger.

Marvin Bolt

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Hoffleit, Ellen Dorrit

Born **Florence, Alabama, USA, 12 March 1907**

American stellar astronomer Dorrit Hoffleit is recognized within the astronomical community both for several decades of maintenance of the *Bright Star Catalog* and for 21 years of directorship of the Maria Mitchell Observatory [MMO]. During the summer programs at MMO more than 100 potential future astronomers worked with her.

Hoffleit was educated in the schools of Pennsylvania and Massachusetts and received a BA (*cum laude*, in mathematics) from Radcliffe in 1928. An interest in astronomy had developed early, when she and her mother saw the 1919 Perseid meteor shower (with an apparent collision between a Perseid and a sporadic meteor), and she eagerly accepted a position at Harvard College Observatory, initially working with **Henrietta Swope** on variable stars. The Harvard system encouraged observatory workers to pursue graduate studies. Hoffleit received an MA in 1932 for work on meteors with

Willard Fisher. The following year, director **Harlow Shapley** urged her to continue toward a Ph.D., and **Bart Bok**, another early mentor, seconded this with vigor. Hoffleit completed a thesis on stellar spectroscopy, under Shapley's direction, in 1938. She received the Carolyn Wilby Prize for the best original dissertation work in any department at Radliffe.

At the outbreak of World War II, Hoffleit turned from work on stellar parallaxes, supernovae, meteors, and spectroscopy to the computation of army artillery firing tables working for **Zdeněk Kopal**. For the following 5 years (1943–1948) Hoffleit worked at the army's Aberdeen Proving Ground, ending with work on Doppler tracking of captured V-2 rockets. While initially given a job rating and salary considerably below those of men with comparable skills and responsibilities, Hoffleit's contributions were eventually well recognized, so that she had to take a major pay cut to return to Harvard.

Hoffleit's postwar work at Harvard focused on the determination of spectroscopic parallaxes of stars, and was regarded as important by both director Shapley and the "dean of American astronomers" **Henry N. Russell** at Princeton. Shapley retired in 1952, and his successor, **Donald Menzel** was not particularly interested either in the Harvard plate collections of images and spectra or in what could be done with them. Increasing friction at Harvard led Hoffleit to a semester of teaching at Wellesley College and from there to a position at Yale University Observatory, where she worked under **Dirk Brouwer** on cataloging the proper motions of southern stars. A second major project there was preparing the third edition of *the Yale Catalogue of Bright Stars* (published in 1964, with new cross-references to other catalogs and additional information on individual stars). The fourth edition, a collaboration with Carlos Jaschek, appeared in 1982. She also collaborated (post-retirement) in the fourth edition of the *Yale Parallax Catalogue* with William van Altena and John Lee (published 1995), and prepared a history of astronomy at Yale.

In 1957, Hoffleit also replaced Margaret Harwood (1885–1979) as director of the Maria Mitchell Observatory (established privately to honor America's first woman astronomer, **Maria Mitchell**) on Nantucket Island, from May to October each year. As part of the appointment process, Hoffleit presented to the board of managers a plan for employing each year a number of young women, interested in astronomy to work on variable stars and other projects possible with the small available telescopes. A number of outstanding astronomers were products of that program, which, by the time of Hoffleit's retirement in 1978, included young men among the observers. The Maria Mitchell Observatory was able to offer hospitality for meetings to the American Association of Variable Star Observers [AAVSO] (the largest society of serious amateur astronomers in the world) several times beginning in 1958. (Menzel did not like AAVSO much either and withdrew Harvard facilities that had been available to AAVSO since 1918.) Hoffleit was elected AAVSO president for 1961/1962.

Hoffleit received an honorary D.Sc. from Smith College (1984) and a variety of other university and professional society awards, including the George Van Biesbroeck Award (1988) for service to astronomy. She is one of 55 Harvard people, 34 Yale people, 11 Maria Mitchell people, and at least 38 people associated with AAVSO to have had asteroids named for them. Her publication list includes several hundred short news items prepared for *Sky* & *Telescope* between 1941 and 1956 and about 450 longer items published between 1930 and 2002.

Elliott Horch

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Hoffmeister, Cuno

Born **Sonneberg, (Thuringia), Germany, 2 February 1892**
Died **Sonneberg, (Thuringia), Germany, 28 January 1968**

German observational astronomer Cuno Hoffmeister is remembered for beginning the series of sky patrol plates at Sonneberg, invaluable in tracing the history of asteroids, variable stars, and so forth; and, less happily, for a theory of interstellar origin for meteors. He was the son of manufacturer Carl Hoffmeister and his wife Marie; his daughter Eva Meyer-Hoffmeister is also an astronomer. Despite having to work in his father's toy factory, young Hoffmeister developed an early interest in astronomy, beginning to observe meteor swarms and variable stars and publishing his first paper (on aurorae) in 1909.

During World War I, Hoffmeister had a job at the Bamberg Observatory under **Carl Hartwig**, working on an extensive bibliography of variable stars and concentrating on adding new information about those whose types and periods were unknown. Having no astronomical qualifications, he had to leave this position after the war ended in 1918, and decided to build his own observatory. The first (1919) site at his father's house was not satisfactory, and he moved to the hill Erbisbuhl above Sonneberg, serving as unpaid head of what became the municipal observatory when it opened in 1925. Hoffmeister gave paid lectures in both English and astronomy and completed a degree in 1927 at the University of Jena.

In 1928, together with **Paul Guthnick** of the Berlin-Babelsberg Observatory, Hoffmeister began sky patrol plates, eventually leading to one of the largest plate archives in the world. From these, 10,926 variable stars have been discovered, 9,646 by Hoffmeister himself, largely using a stereocomparator of his own design. He first leased the observatory to the state, and later sold it, but remained director until 1967, and had just completed a monograph on variable stars at the time of his death.

In addition, Hoffmeister discovered several asteroids (one of which bears the name (4183) Cuno) and photographed and measured meteors, zodiacal light, aurorae, noctilucent clouds, polarization of sky light, and comets, including Whipple–Fedtke–Terzadze (C/1942 X1), from which the existence of the solar wind was deduced before it was measured. He organized five expeditions to the Southern

Hemisphere, beginning the first southern sky patrol series, which proved important in identifying the progenitor of Supernova 1987A in the Large Magellanic Cloud. Hoffmeister was initially a supporter of the idea that meteors came from interstellar space on the basis of some apparently large velocities, but reappraised his ideas in 1948.

Miloslav Zejda

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Hogg, Frank Scott

Born **Preston, Ontario, Canada, 26 July 1904**
Died **Richmond Hill, Ontario, Canada, 1 January 1951**

Canadian astronomer Frank Hogg was the director of the David Dunlap Observatory and investigated spectroscopic binaries. His thesis advisor **Cecilia Payne-Gaposchkin**, his wife **Helen Sawyer Hogg**, and Hogg were the first three Ph.D.s in astronomy from Harvard University.

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Hogg, Helen Battles

➔ **Sawyer Hogg, Helen Battles**

Holden, Edward Singleton

Born **Saint Louis, Missouri, USA, 5 November 1846**
Died **West Point, New York, USA, 6 March 1914**

Edward Holden directed the Washburn Observatory at the University of Wisconsin, and helped design and served as the first director of the Lick Observatory of the University of California. He also organized the Astronomical Society of the Pacific and served as its first president.

Holden was the son of Edward and Sarah Frances (*née* Singleton) Holden. After his mother and a sister died of cholera when he was only 3 years old, Holden was raised by his father for a few years and then sent to Cambridge, Massachusetts, where he received his elementary education in a private school run by a cousin while living with his paternal aunt. His father died, also of cholera, when Holden was 19. As a community, Cambridge provided a rich environment for the maturing young Holden as he developed an appreciation of music and literature in addition to exploring his interest in astronomy with his cousin by marriage, **George Bond**, director of the Harvard College Observatory. He returned to Saint Louis to attend the Washington University Academy for 2 years before matriculating from the university. He studied astronomy and mathematics with the well-known astronomer and university chancellor **William Chauvenet**. Holden lived for 1 year with the Chauvenet family; he fell in love with the astronomer's daughter Mary, whom he married in 1871.

After receiving his Bachelor of Science degree in 1866, Holden was appointed to the United States Military Academy [USMA] at West Point. Following his graduation in 1870, when he was ranked third in his class, he was commissioned a lieutenant and served for a year in the Fourth Artillery Regiment. He was then ordered back to the USMA to teach mathematics and fortifications. In 1873, Holden resigned his army commission and accepted a commission as professor of mathematics in the United States Navy, assigned to work as an astronomer at the Naval Observatory in Washington, DC. Working for **Simon Newcomb**, Holden had access to the Naval Observatory's new 26-in. Alvan Clark refractor, made famous by **Asaph Hall**'s 1877 discovery of the two satellites of Mars. Holden used the 26-in. to observe the planets and their satellites, comets, double stars, and nebulae.

When D. O. Mills, president of James Lick's board of trustees, visited Washington in 1874, Newcomb recommended that the trustees appoint the observatory's first director at an early date and suggested that Holden could be a candidate. Newcomb and Holden prepared detailed plans for the Lick Observatory, with Newcomb providing the concepts and Holden reducing those to paper in text and drawings. The Lick Observatory trustees accepted the proposed design essentially intact. Holden secured his selection as the first director mainly by his efforts in this design phase, and also by impressing Mills's successor, captain Richard S. Floyd, when the two met in London in 1876.

In 1881, with litigation of the Lick Estate holding up construction of the observatory, Holden was offered and accepted the directorship of the University of Wisconsin's Washburn Observatory. At Washburn, Holden made an important study of Saturn's rings (from his own observations and those of others), prepared catalogs of red stars and stars in the southern sky, and encouraged **Sherburne Burnham** to discover new double stars using Washburn's 15-in. Clark refracting telescope. Holden also made some of the earliest statistical studies of stellar distribution from the star charts of other observers such as **Christian H. Peters**.

In anticipation of his appointment as the Lick Observatory director, Holden accepted an appointment as president of the comparatively new University of California in Berkeley in 1885. While president, he established a department of biology and the first marine biology laboratory on the West Coast, and started a program in journalism, which he observed was becoming a profession.

In 1888 Holden was named the first director of the new Lick Observatory on Mount Hamilton, California. At that time Lick boasted the largest refractor in the world, a 36-in. instrument with a primary lens made by Alvan Clark & Sons. Holden oversaw the production of a lunar atlas from photographs taken by him and others with the 36-in. telescope, and made occasional visual studies of the planets and nebulae. However, he was principally Lick's administrator, doing little original astronomical research, but supervising what was, at that time, probably the most talented group of observational astronomers ever assembled. Holden's staff included Burnham, **Edward Barnard**, and **James Keeler**.

Holden was the major force behind the founding, in 1889, of the Astronomical Society of the Pacific, an organization that brought together amateur and professional astronomers to increase the public understanding and appreciation of astronomy. He also founded and edited the *Publications of the Astronomical Society of the Pacific*. Holden took a leadership role in several total solar-eclipse expeditions that produced valuable visual and spectroscopic data for the solar corona. During these eclipses, his own systematic searches for Vulcan, a hypothetical planet thought to be orbiting the Sun inside the orbit of Mercury, definitively showed that no such planet existed. Holden conducted similar expeditions to observe transits of Mercury (1881) and Venus (1882).

Holden's major original scientific contribution at the Lick Observatory was probably his 1887 installation of the first seismographic station in the Western Hemisphere at the observatory; that same year Holden published the first comprehensive catalog of California earthquakes.

Holden was one of the few astronomers in his era who understood the limitations of the astronomical refractor and the benefits associated with the astronomical reflector. Thus, when he learned that the British amateur astronomer Edward Crossley (1841–1905) planned to sell his 36-in. reflector and its dome, Holden persuaded Crossley to donate the telescope to Lick Observatory; it arrived at Mount Hamilton in 1895. Although substantially modified by Keeler on his return from the Allegheny Observatory to become the second director of the Lick Observatory, the Crossley Telescope played a major role in persuading the astronomical community of the merits of large reflecting telescopes. In Holden's case, however, what should have been a triumphant acquisition turned instead to ashes as the assembly and start-up of the telescope became his own undoing.

Though he was acknowledged as a brilliant organizer and administrator, in his zeal to perfect a military-like discipline among the observatory staff, Holden proved to be an ineffective small group leader in the difficult mountain top environment. The petty disenchantment of all involved snowballed into crisis after crisis that spilled over into an unprecedented public display of rancor and bitterness. In what could only be called a revolt, some of the staff astronomers at Lick expressed their growing grievances with Holden in the local newspapers. The difficulties demanded the attention of the university regents after resignations of Burnham, followed by spectroscopist Henry Crew who had been hired to replace Keeler, and finally Barnard. When a new staff astronomer, **William Hussey**, refused to work on the Crossley telescope and appealed directly to the regents for their intervention, Holden was forced to resign in September 1897.

After leaving Lick, Holden spent 4 years in New York City, struggling to support his family as a freelance writer. In 1901, he returned to West Point as the USMA librarian, publishing many books and monographs on mostly historical topics. He became a beloved contributor to academy life, and was buried there with full military honors.

In spite of the fractious disputes that ended his tenure at the Lick Observatory, Holden received many honors for his contributions to science including election to the National Academy of Sciences in 1895. He was awarded honorary doctorates by four American universities.

Peter Wlasuk

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Höll, Miksa

Born **Selmecbánya (Bánska Stiavnica, Slovakia), 15 May 1720**
Died **Vienna, (Austria), 14 April 1792**

Maximilian Hell (Höll) was a Hungarian astronomer whose reputation was tarnished because of his observations of the transit of Venus. He was the son of Máté Kornél Hell, a well-known mathematician and mine technician, and Julianna Viktória Staindl. Hell entered the Society of Jesus in 1738 and was sent to Vienna to study philosophy at the university. From 1744 he studied mathematics and astronomy and served as an assistant in the Jesuits' observatory of Vienna. Hell spent 1 year in Locse (Levoca, now Slovakia) as a teacher, and in 1747 he returned to Vienna to study theology. He was ordained priest in 1752, then became the professor of mathematics in Kolozsvár (Klausenburg, now Cluj-Napoca in Romania). In 1755 Hell was appointed professor of mechanics at the university and director of the new observatory in Vienna.

Although he lived in Vienna, Hell had close connections with Hungarian astronomers. Four observatories were built under his guidance (Nagyszombat, 1755; Eger, 1776; Buda, 1780; Gyulafehérvár, 1792). Hell was commissioned to organize the Vienna Academy of Sciences. In consideration of his services, he was elected a member of several academies in Europe.

Hell's most important achievement was the annual publication of the *Ephemerides astronomicae ad meridianem Vindobonensem* published between 1757 and 1791. This was the second astronomical yearbook in Europe.

Hell's other major impact on astronomy at large was the observation of the transit of Venus on 3 June 1769 and the determination of the solar parallax. He was invited by Christian VII, King of Denmark, to observe the transit from Vardø. Since the island of Vardø was the northernmost location from where the transit was followed, Hell's observations were critical from the point of view of the accuracy of the value of the Sun–Earth distance. Hell delayed in publishing the results because at first he wanted to show them to his royal patron. **Joseph de Lalande**, who was to collect the observational data from each observing site, accused Hell of manipulating the data because of the delayed submission, thus destroying Hell's reputation.

In 1835 (decades after Hell's death) **Karl Littrow** scrutinized Hell's notes written during the transit and found that the moments had been corrected in ink of different color, lending further support to forgery. In 1883, however, **Simon Newcomb** checked Hell's manuscripts kept in Vienna and came to a different conclusion. The temporal data were corrected during observing the transit in Vardø in order to make the notes written in faint ink (due to Arctic cold weather) legible. Newcomb revealed that the corrected figures were of the same color, only the shade altered during drying. He also noted that it was obvious from Littrow's astronomical observations that Littrow himself could not distinguish colors properly. Hell was fully rehabilitated by Newcomb's 1883 paper. From his own data, Hell deduced 152 million km for the mean value of the Sun–Earth distance. (The modern value is 149.6 million km.)

Hell also wrote textbooks on mathematics (*Elementa algebrae Joannis Crivelli magis illustrata*, Vienna, 1745 and *Elementa arithmeticae numericae et litteralis*, Vienna, 1763), and in his last years, he dealt with studies of healing properties of magnetism with Franz Mesmer. His ill-fated career has to do with the suppression of the Jesuit Society during a power struggle in 18th-century Europe.

A crater on the Moon is named for Hell. From the point of view of science history, it is noteworthy that during the Vardø expedition, Hell's assistant, János Sajnovics, S.J., pointed out the common origin of the Lapp and Hungarian languages.

László Szabados

Alternate name

Hell, Maximilian

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Holmberg, Erik

Born **Tofteryd, Sweden, 13 November 1908**
Died **Gothenburg, Sweden, 1 February 2000**

Swedish galactic astronomer Erik Holmberg gave his name to the Holmberg radius or diameter (the effective size of a galaxy measured at a particular level of apparent brightness in the sky), and to the Holmberg effect (the observation that small satellite galaxies orbiting big ones are more likely to be found around the poles than near the equatorial plane of the large galaxy), but his most lasting contribution was probably the demonstration that the measured masses for orbiting pairs of galaxies are larger than those of the individual galaxies measured from their own rotations but smaller than the total mass implied by clusters of galaxies.

Holmberg was the son of Malcolm and Anna (*née* Nilson). He married Martha Asdahl in 1947, and their daughter Osa was born in 1953.

Holmberg finished his Ph.D. thesis on double and multiple galaxies in 1937 at Lund University, where he was a student of **Knut Lundmark**. From 1937 to 1951 Holmberg was assistant professor and then associate professor at Lund university, being noted throughout his career as an inspiring teacher. From 1959 until his retirement in 1975, Holmberg was professor and director of the Uppsala Observatory. An experienced observer, Holmberg traveled extensively to obtain observational data. He visited the Heidelberg Observatory in 1935/1936 for his thesis and a number of astronomical institutes in the USSR and European observatories between 1936 and 1977. Holmberg was a guest investigator at the Mount Wilson and Palomar observatories numerous times between 1939 and 1968 and a guest lecturer and visiting professor at many American observatories and universities including Wesleyan. He was active in the International Astronomical Union [IAU].

Holmberg was one of the leading pioneers in extragalactic astronomy. While he contributed to stellar astronomy, the subject of galaxies was his lifelong interest. In his 1937 Ph.D. thesis, Holmberg showed statistically that most near galaxy pairs are physically related, a fact that he showed could be combined with radial velocity measurements to determine galaxy masses. He was one of the first to consider determining galaxy masses from rotation curves. Starting in 1945 Holmberg conducted an extensive program of galaxy photometry using precision photographic techniques resulting in his classical catalog of data for 300 galaxies published in 1958. In this fundamental work Holmberg defined the outer boundary of a galaxy to be the isophote at 26.5 photographic magnitude, per square arcsecond now referred to as the Holmberg radius. Holmberg utilized his work to determine the galaxy luminosity function and better understand galaxy structures including corrections for their internal dust. He also discovered the Holmberg effect that significantly more satellite galaxies lie in projection above the poles of spiral galaxies than there are along their equators.

Holmberg was one of the first to theoretically consider galaxy collisions. In 1941 he constructed an analog computer consisting of light bulbs and photoelectric cells to simulate the inverse square law of gravity and followed the collision of two galaxies.

Holmberg was involved in completing two monumental galaxy catalogs: the Uppsala General Catalogue of Galaxies conducted in 1973 by his student Peter Nilson and the European Southern Observatory [ESO]/Uppsala Survey of the ESO (B) Atlas with Andro Lauberts, Hans-Emil Schuster, and Richard M. West, which have greatly added to the knowledge of galaxies and cosmology.

Holmberg served as president of the Commission on Galaxies (28) of the IAU (1973–1976), was elected to the Royal Academy of Sciences of Sweden (1959), and chaired the Swedish Astronomical Society (1964–1972). His waltz with Russian astronomer Alla Massevitch was one of the highlights of the closing banquet of the IAU General Assembly in Brighton in 1970.

Gary A. Wegner

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Holwarda, Johannes Phocylides [Fokkens]

Born **Holwarden, Friesland, the Netherlands, 19 February 1618**
Died **Franeker, Friesland, the Netherlands, 22 January 1651**

Johannes Holwarda's most famous observational accomplishment was his rediscovery of the variable star Mira (o Ceti) in the constellation Cetus.

Holwarda studied in Franeker under Adrian Metius and graduated in 1640 with a doctoral degree in medicine. In 1639, he became a lecturer in logic and was promoted in 1647 to professor of philosophy in Franeker. In addition to philosophy, Holwarda studied theoretical and practical astronomy and worked as a medical practitioner.

In 1640, Holwarda wrote his *Dissertatio astronomica*, in which he examined in great detail the widely used astronomical tables of **Philip Lansbergen**. In this work and according to his own calculations and observations, Holwarda found errors and theoretical mistakes of a considerable magnitude. Holwarda proved to be a persistent defender of **Johannes Kepler**'s planetary theory and celestial physics, which he incorporated into an atomistic philosophy.

David Fabricius had first observed Mira ("wonderful") in 1596 and then again in 1609, after a long period of invisibility. These observations were forgotten until Holwarda rediscovered the star and its variability in 1638. Holwarda showed that this was a recurring process with a period of approximately 11 months. **Johann Hevel** and **Ismaël Boulliau** later found 332 days a better approximation for Mira's period.

Jürgen Hamel
Translated by: *Balthasar Indermühle*

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Homer

Flourished **Ionia, Asia Minor, 8th century BCE**

Homer's epics, the *Iliad* and the *Odyssey*, indicate some familiarity with the sky, and with particular stars and constellations; they also show the stars used for navigation and other activities such as marking the seasons. Despite enormous literary and cultural influence of these Greek hexameter epics, nothing reliable is known about their author, who has traditionally been identified with the poet called Homer. Most scholars now agree that each of the poems themselves represents the work of one individual, even if both works may not be by the same author. The *Iliad* is generally agreed to be the earlier of the two by a generation or so, being dated to the mid-8th century BCE. Oral composition played a major role in the development of both epics, and the extensive use of formulaic phrases by preliterate bards has been shown to be an essential feature of the transmission of these lengthy poems from generation to generation.

While the Homeric epics represent the end stage in a process that reaches back at least four centuries into the Mycenaean Age (*circa* 1600–1200 BCE), where the stories themselves originated, the works also reflect the contemporary world of their singers on the islands of the eastern Aegean and on the mainland region of Asia Minor known as Ionia. This amalgam of historical and cultural material renders any analysis of the specific origins of astronomical concepts represented in the works impossible, although the names of various months appear in Mycenaean Linear B tablets, indicating probable knowledge of lunar and solar cycles.

Neither cosmology nor theogony appears in the epics, clear evidence of an approach to the visible cosmos that simply accepts it rather than trying to explain it. The Earth, whose shape and form are unmentioned, is encircled by the river Ocean (*Il.* 18.607-08). Above the Earth arches heaven (*ouranos*), which is seen as solid (*e. g.*, *Od.* 3.1-2) and is regularly called "starry" (*asteroeis*), as at *Od.* 11.17. It is supported above the Earth on pillars (*Od.* 1.52-4). Through the *aither*, or upper air, the heavenly bodies are seen when the sky is clear (*Il.* 8.555-9); mist (*aer*) lies closer to the surface of the Earth itself (*Il.* 14.287-8).

The Homeric poems evidence an awareness of the basic elements of the sky, of star patterns, and of individual stars. The star clusters of the Hyades and the Pleiades appear, along with the constellations Ursa Major and Orion, in the representation of the world depicted on Achilles' shield (*Il.* 18.606-07). These are also mentioned at *Od.* 5.271-7, as is Boötes. Sirius figures prominently in the *Iliad* and although nowhere is it specifically named, it appears in literary comparisons as the "autumn star" (*aster oporinos*: 5.5-6), as *oulios* ("baleful": 11.62-3), and as "Orion's dog" in a description of Achilles (22.26-31). Homer also recognizes the concept of circumpolar stars by stating that the Bear (*Arktos*) does not dip into Ocean (*Od.* 5.275) as the other stars do (*e. g.*, *Il.* 5.5-6). There is no mention of a pole star or of the Milky Way. Similarly, while the poet incorporates a description of an evening and morning star into the narratives (*Il.* 22.317-18, 23.226; *Od.* 13.93-40), no identification of the planets is acknowledged. A comparison of the goddess Athene to a meteor or comet appears at *Il.* 4.75-8.

Of the Sun, Homer says that it too, like the stars, rises from and sets into Ocean (*e. g.*, *Od.* 3.1; *Il.* 8.485), while attaining its highest point in the middle of the sky (*Od.* 4.400; *Il.* 16.777). The Moon's phases are not noted specifically but must have been used if the lunar cycle formed the basis for monthly time measurement. East and west are marked by the Sun's rising and setting (*Od.* 10.190-92), although no astronomical bearings are evident for north and south. The day is seen as tripartite, morning, midday, and afternoon (*Il.* 21.111; *Od.* 7.288), as is the night, but with less specificity (*Il.* 10.251-3; *Od.* 12.312).

Homeric epic offers a sometimes confusing picture of the seasons and of the passage of time in general. While the years are described as "revolving" (*peritellomenoi eniautoi*), there is no stated beginning of the year proper. Three seasons, winter, spring, and summer, are recognized but not delimited with any precision, although early autumn may be considered distinct from the last (*e. g.*, *Il.* 22.27). The length of the day in winter and summer is not differentiated; nor is there a definite concept of the solstices, despite the mention of the "turnings of the Sun" (*tropai helioio*) at *Od.* 15.404 and "long days" (*emata makra*) in a line of dubious authenticity (*Od.* 10.470).

In sum, the Homeric poems reveal a clear familiarity with heavenly phenomena but a scant association made with their actual causes. Some stars and constellations are recognized and named, while the planets themselves are hardly noticed as independent entities. Although the celestial bodies are not considered divine in and of themselves, there is some suggestion that stars could affect the human condition (*e. g.*, Sirius). The passage of time, particularly that of the seasons and the years, is seen as related to the state of the heavens, indicating a growing awareness of the importance of astronomical observation for human activities and affairs.

John M. McMahon

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Honda, Minoru

Born **Tottori Prefecture, Japan, February 1913**
Died **Kurasashiki, Japan, 26 August 1990**

Japanese amateur astronomer Minoru Honda discovered more than a dozen comets, in turn mentoring a younger generation of remarkably successful Japanese comet hunters. After attending a primary school and its 2-year extension course, Honda started to work with his parents as a farmer. However, already in his school days he had been interested in astronomy, and he made his first telescope in 1927 using a purchased 28-mm lens. When Honda was 17 years old, he read the book on comets by Shigeru Kanda and knew that no comet had yet been discovered in Japan. Immediately Honda decided to discover one and started to make observations without any stellar chart.

In 1937 Honda was hired by Issei Yamamoto, the founder of the Oriental Astronomical Society, to work at the Zodiacal Light Observatory in Seto Hiroshima. There Honda discovered, in October 1940, comet C/1940 S1 (Okabayasi–Honda), which was detected by S. Okabayasi at the Kurashiki Observatory in Okayama Prefecture 3 days before. In January 1941 he discovered comet C/1941 B1 (Friend–Reese–Honda). When Okabayasi left Kurashiki, Honda took over his position there in April 1941. Okabayasi was killed in 1944 by a submarine attack off Taiwan on his way back from Indonesia, where he was engaged in a geological survey.

In July 1941 Honda was drafted by the army as a soldier and was sent to the northeastern district of China and then to Singapore through Malaysia. Even during his military service days he always carried a monocular and observed stars. In Singapore Honda acquired an 8-cm lens and made a telescope, by which he discovered a comet in May 1947. However, it happened to be 25P/Grigg–Skjellerup, a periodic comet, which had been already recovered by **George van Biesbroeck** and Kanda before him. Still Honda's observation was reported by newspapers in Japan.

Honda came back to Kurashiki in May 1946, and in November 1947 he discovered C/1947 V1 (Honda). However, because Japan was then occupied by the Allied Forces, Japanese could communicate with foreign countries only by mail. The director of the Tokyo Astronomical Observatory asked the Allied Forces to report the discovery to the International Astronomical Union Central Bureau of Astronomical Telegrams in Copenhagen. After that Honda independently discovered comets C/1948 L1 (Honda–Bernasconi), 45P/Honda–Mrkos–Pajdusakova, C/1953 G1 (Mrkos–Honda), C/1955 O1 (Honda), C/1962 H1 (Honda), C/1964 L1 (Tomita–Gerber–Honda), C/1968 H1 (Tago–Honda–Yamamoto), C/1968 N1 (Honda) in July 1968, and C/1968 Q2 (Honda). The discoveries before 1965 were made by the 15-cm reflector except for C/1948 L1, which was a naked-eye discovery. The other three in 1968 were discovered using the 12-cm binocular.

Honda's comet discoveries were widely taken up by newspapers in Japan and encouraged Japanese people in those gloomy days after World War II – particularly young people, including Kaoru Ikeya and Tsutomu Seki, who started to search for comets. Both of them wrote letters asking Honda's advice before they succeeded in discovering the first comets.

In February 1960 Honda started photographic observations to search for novae. The first successful discovery was made in February 1970. Honda discovered 11 novae, the last of which was in January 1987. One of them, namely the very bright nova in Cygnus in August 1975, was discovered with the naked eye.

After 1965 Honda served as the director of two kindergartens in Kurashiki. In his later years he did not make observations in Kurashiki because of light pollution. Finally in 1981 Honda built a small observatory, 30 km north of Kurashiki, which he visited 1,451 times, the last time being 2 days before he died.

Yoshihide Kozai

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Honter, Johannes

Born **Kronstadt, (Brasov, Romania), 1498**
Died **Kronstadt, (Brasov, Romania), 23 January 1549**

Unlike fellow German uranographer **Albrecht Dürer**, Johannes Honter drew constellation figures as if they were to be seen from the Earth below, instead of from "above."

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Hooke, Robert

Born **Freshwater, Isle of Wight, England, 18 July 1635**
Died **London, England, 3 March 1703**

Robert Hooke was one of the foremost experimenters of the 17th century and a remarkable inventor of astronomical instruments. He was among the first to suggest the inverse-square law of gravitation and the periodicity of comets.

Hooke was the son of John Hooke, curate of All Saints Church in Freshwater, and his second wife Cicely Giles. A sickly child, he was not expected to survive childhood.

At a young age Hooke showed artistic and mechanical talent; he could draw and paint and build wooden models of machines that worked. When he was 13, his father died, and Hooke was sent to London to be apprenticed to the portrait painter Sir Peter Lely, but the odor of the oil paint made him sick. He was then sent to Westminster School. The headmaster, Dr. Busby, immediately recognized the boy's genius when Hooke learned the first six books of Euclid in a week, taught himself to play the organ, and learned several languages besides Latin and Greek. Mathematics, however, was his favorite subject.

In 1653 Hooke was admitted to Oxford University (Christ Church). Oxford was then scrutinized by a parliamentary committee. Its atmosphere would have been restrictive but for men like **John Wilkins**, Warden of Wadham College. Hooke became a protégé of Wilkins who gathered around him an extraordinary group including **Christopher Wren** and Robert Boyle, regardless of political or religious affinities. Their purpose was to study the natural world through experimentation and observation. When Boyle set up his chemical laboratory, Hooke became his assistant and designed and built an air pump. He also succeeded in proving the relation of gas pressure to volume, known as Boyle's law. At the same time Hooke studied astronomy under the guidance of **Seth Ward**, Savilian Professor of Astronomy.

Charles II was restored in 1660, and the newly formed Royal Society of London soon after received its charter. On Wilkins's recommendation in 1662 Hooke was appointed Curator of Experiments at the Royal

Society, essentially sustaining its existence with his lectures and experiments; he was elected fellow in 1663. In 1665 he was appointed Professor of Geometry at Gresham College, London, where he was given lodgings. The Royal Society met in his rooms. In 1677 Hooke became secretary of the society when Henry Oldenburg died, while retaining his curatorship throughout his life. He contributed significantly to physics, astronomy, chemistry, geology, biology, paleontological and biological evolution, meteorology, horology, architecture, cartography, and many other areas. In 1691 Oxford honored him with the degree of "Dr. of Physick." Because during his life Hooke had been involved in some scientific disputes over priority, notably with **Isaac Newton**, history has not been kind to him, so that his name is known today only for his eponymous law.

In astronomy Hooke sought to improve instrumentation for more accurate measurements. Hooke's inventions in horology were designed to assist in the determination of longitude. In 1656 he invented the anchor escapement to replace the verge or crown wheel for better accuracy in clocks. In 1658, he invented the balance wheel for pocket watches using springs instead of gravity for vibrations in any position. Hooke designed micrometers and devised the technique of screw turns to measure minute differences in angles and distances. He invented the universal joint for more efficient ways to operate telescopes and other instruments where accurate rotational movement is needed. In addition, Hooke invented the use of telescopic sights, the clock-driven telescope, and the iris diaphragm. When Greenwich Observatory was built in 1675 he supplied it with instruments he designed.

On 9 May 1664, using his 12-ft telescope Hooke discovered a giant spot on Jupiter. He observed that within 2 hours the spot had moved from east to west about half the planet's diameter, demonstrating the planet's rotation. Studying rotating bodies, Hooke devised experiments that indicated the shape of the Earth to be an oblate spheroid with the longer dimension around the Equator. This shape was the cause for the slowing of pendulum clocks carried on ships as they approached the Equator. The Earth's shape is relevant to geology, a science for which he essentially laid the foundation.

Hooke observed the lunar surface and theorized on the causes of the formation of craters. To produce craters, he shot bullets onto a surface of clay and boiled a pan of liquid alabaster, demonstrating the cause to be either by impact or steam explosions, two ideas that were hotly debated by geologists long after. He published these findings in his famous book *Micrographia*, which contained a wealth of ideas and depictions of never-before-seen things he saw through the microscope he built. Hooke tracked the path of comet C/1664 W1 and lectured on it at the Royal Society, suggesting it was the return of one of the 1618 comets. This was many years before **Edmond Halley** proposed periodicity of comets.

During the years 1666–1667, Hooke was deeply involved in rebuilding London after the Great Fire. As City Surveyor, he worked in partnership with **Christopher Wren**, having designed the Great Dome of Saint Paul's Cathedral and other famous structures without credit. As busy as he was, however, Hooke continued to improve his instruments, give lectures and demonstrations, and observe the skies deep into the night. His 30-ft. telescope went through two floors of his lodging at Gresham College, with a wooden trapdoor for poking the telescope through the roof.

The vertical position was chosen to minimize tube flexure and atmospheric effects in his unsuccessful effort to measure stellar parallax.

The most profound disappointment of Hooke's career was not having been accorded credit for his part in discovering the nature of planetary motions, the law of gravitation. As early as 23 May 1666 Hooke wrote:

> I have often wondered why the Planets should move about the Sun according to Copernicus … [being not] tyed to it, as their Center, by any visible strings, … nor yet move in a streight line, as all bodies, that have but one single impulse ought to doe: But all the Celestiall bodies [moving in] Circular or Elliptical Lines, and not streight, must have some other cause, besides the first imprest Impulse, that must bend their motion into that Curve….

Notice that implicit in this statement is Newton's first law. By 1670, he was certain that the cause of deflecting a body into a curve is "an attractive property of the body placed in the centre whereby it continually endeavours to attract or draw it to itself," and planetary motion can be explained by mechanical principles and calculated "to the greatest exactness and certainty that can be desired." Hooke communicated this important idea of a centripetal force to Newton in a letter in 1679. Newton admitted in his reply that he had never thought of such a concept before receiving Hooke's letter. Hooke noted in his diary for 4 January 1680, "perfect Theory of Heavens," with obvious satisfaction that he had solved a universal mystery. In Richard Westfall's opinion, universal gravitation was inconceivable without the concept of centripetal force, and that was Hooke's contribution. Newton, however, would never acknowledge this debt in the several editions of the *Principia*.

Ellen Tan Drake

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Hörbiger, Hanns

Born **Vienna, (Austria), 29 November 1860**
Died **Vienna, Austria, 11 October 1931**

Austrian mining engineer Hanns Hörbiger was observing the Moon through a small telescope when he imagined that he saw a lunar surface made of ice. This idea snowballed into publication of *Glazial-Kosmogonie* (1913), cowritten with **Philipp Fauth**. Hörbiger's frozen cosmology required, among other unorthodox things, that the Sun's gravitational force cease at precisely three times the distance of Neptune. The cosmic ice theory was popular with many Nazis, who saw in it a paragon of "Nordic science."

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Horn d'Arturo, Guido

Born **Trieste, (Italy), 13 February 1879**
Died **Bologna, Italy, 1 April 1967**

Italian observational astronomer Guido Horn d'Arturo designed and built the first segmented or tessellated telescope. He came from a Jewish family, probably of Dutch extraction, and was originally named Guido Horn. He completed his studies at the University of Vienna, an important crossroads for both science and culture during that period, graduating in 1902.

Horn began his career in 1903 at the Astronomisches und Meteorologisches Observatorium of Trieste and later moved to the Catania Observatory, where he remained until 1910. During this period, Horn was involved mainly in observing and studying the Sun, comets, and variable stars, and contributing actively to the *Carte du Ciel*, an international initiative for the photographic study of the heavens. In the 2-year period of 1910–1911, he worked in Turin as the assistant astronomer, and during his stay in Turin he published several articles in one of Italy's first and most important popular astronomical journals, the *Rivista di astronomia e scienze affini*. In 1911 Horn went to Rome, and in 1912 he was appointed assistant at the University Astronomical Observatory of Bologna, headed by Michele Rajna.

When World War I broke out, Horn enlisted as a volunteer in the Italian army, rising to the rank of artillery captain by the end of his service. At the time, his hometown of Trieste was still part of the Austro – Hungarian Empire, and in order to avoid possible retaliation by the Austrians, he changed his surname to "d'Arturo," after his father. Following the war, he filed a request with the Italian government to make his double last name official, thus becoming Horn d'Arturo.

Upon Rajna's death in 1920, Horn was appointed director of the Bologna Observatory and professor of astronomy at the university, winning the chair of astronomy in 1921. He intensely promoted the scientific revival of the observatory, remaining at its helm until 1938, when he was forced to resign because of racial persecution due to his Jewish background. Reinstated following the war, Horn was again appointed director of the observatory and was awarded the chair at the university, remaining there until he retired in November 1954. In the years that followed, he continued to participate actively in the work of the astronomical institute, overseeing publication of the journal *Coelum* and the organization of the library.

Horn had numerous multifaceted interests, encompassing nearly all the sectors of astronomy and involving a large number of subjects. He was interested in positional astronomy as well as statistical astronomy, astrophysics, and cosmology, conducting research on solar eclipses, our own Galaxy, the galactic nebulae and the external galaxies, the synchronization of clocks at mean local time and mean sidereal time, problems of photographic and physiological optics, and the design of new optical instruments.

In 1921 he began the series of *Pubblicazioni dell'Osservatorio dell'Università di Bologna*, which were only published when a work produced by the Bologna Observatory was definitive and could thus be considered official. Particularly important publications concerned segmented telescopes, the use of a conical lens rather than an objective prism to obtain spectra of stars and comets, and an explanation of the apparent fluctuations of the solar limb and shadow bands seen on all white surfaces just before the beginning of a total solar eclipse. His explanation, later verified by studies of the same phenomena for starlight, was scintillation (twinkling, or differential refraction) of the narrow remaining strip of sunlight in currents of varying density in the Earth's upper atmosphere. In 1925 Horn set up and directed an expedition to Somalia to observe the total eclipse of the Sun on 14 January 1926. He organized another expedition in 1936 to observe the total eclipse of the Sun visible in the Peloponnesus.

Horn also dedicated himself to reorganizing and adding to the observatory library, helping to establish a priceless legacy not only in terms of new acquisitions but also with the purchase of a considerable number of antique books. Because of his efforts, the new library building of the Department of Astronomy of Bologna was dedicated to him in 1999. Horn's passion for astronomy was also manifested in his work to promote this field. In 1931 he founded the journal *Coelum* to spread and popularize astronomy. After Horn's death, the periodical, which gained enormous circulation not only in Italy but also internationally, continued to be published until 1986.

Horn was committed to bringing the field of astronomy at the University of Bologna back to a level worthy of its traditions, striving to equip the observatory with suitable astronomical instruments. A sizeable donation made it possible to purchase a new Zeiss reflecting telescope with a diameter of 60 cm and a focal length of 210 cm. On 15 November 1936 Horn inaugurated the new observation station of the Bologna Observatory, located about 18 miles from the city in Loiano, in the Apennines, at an altitude of 800 m above sea level. Although it was smaller than the 1-m reflecting telescope at the Milan Astronomical Observatory in Merate, the new telescope was installed in a spot that was astronomically more favorable, making it an excellent research laboratory for an entire generation of Italian and European astronomers.

The desire to improve the set of available instruments, coupled with the failure to obtain the necessary funds, led Horn to study the construction of telescopes with compound mirrors. This also avoided the problem that a very large mass of optical glass would bend under its own weight, distorting the shape of a mirror or lens. Horn's idea was to make large reflecting optical surfaces by combining a set of small mirrors, machined optically and positioned so as to form a single image of each star. The image was obtained by having the rays that were reflected by the individual mirrors converge onto a single focal plane.

The first tessellated telescope, built by Horn in 1935, had an aperture of 1 m and a focal length of 10.5 m. It was installed in the upper room of the ancient observatory tower in the center of Bologna under a 1.2-m hole made in the roof in 1725, used for zenith observations with the long telescopes of the era. After the war, Horn started to construct a new mirror, and in 1953 he completed the instrument, composed of 61 small mirrors for a total aperture of 1.8 m, a focal length of 10.4 m, and a useful field of view of 39 × 26′.

To position the telescope, an opening was made through four floors of the tower. Using this instrument, over 10,000 plates were exposed, yielding a systematic survey of the zenithal sky of Bologna. Horn successfully photographed stars beyond the 18th magnitude with a maximum exposure time of 6 min and 45 s, leading to the discovery of about ten new variable stars. Both mirrors are now in the Astronomical Museum of the University of Bologna (Museo della Specola), which exhibits the instruments used by Bologna astronomers since the 17th century. The technique invented by Horn was adapted in the late 20th century for the Multiple Mirror Telescope [MMT], composed of six mirrors, each with a diameter of 1.8-m, set on the same altazimuth mounting on Mount Hopkins in Arizona. Above all, it was also used for the twin telescopes at the Keck Observatory on Hawaii's Mauna Kea volcano. Each telescope is composed of 36 1.8-m mirrors, forming a mosaic with an overall diameter of 10 m.

Horn's manuscripts and part of his private archives, donated by his heirs, are in the Historical Archives of the Department of Astronomy of the University of Bologna.

Fabrizio Bònoli

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Hornsby, Thomas

Born **Oxford, England, 1733**
Died **1810**

Savilian Professor of Astronomy Thomas Hornsby founded the Radcliffe Observatory at Oxford. Yet his major contribution to astronomy was not as an observer: It was Hornsby who reduced the data collected worldwide from the 1769 transit of Venus.

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Horrebow, Christian

Born **Copenhagen, Denmark, 15 April 1718**
Died **Copenhagen, Denmark, 15 September 1776**

Christian Horrebow belongs to the pioneers of systematic sunspot observation. Horrebow was the son of **Peder Horrebow**. In 1754 he married Anna Barbara Langhorn (1735–1812).

Horrebow became a student at the University of Copenhagen in 1732 and obtained the master's degree in 1738. He assisted his father at the observatory, and from about 1740 gradually took over his father's tasks as professor and observatory director, where finally, in 1753 he officially replaced him. He was a member of the Copenhagen Science Academy.

Generally the epoch during which Horrebow observed was one of stagnation in Danish astronomy, and the scientific achievements are quite few. He made attempts to organize observations of the Venus transits in 1761 and 1769, but these were unsuccessful because of unsatisfactory instruments and bad weather. On the other hand, Horrebow began fairly regular sunspot observations in 1738 and continued these until his death. He hoped to find a period in the sunspot activity, but his data series did not suffice.

Regular time service by a signal from the observatory at the Round Tower was initiated in 1772. Horrebow insisted on signaling true solar time, not mean time, causing confusion and indignation among the Copenhagen population. This awkward practice nevertheless persisted until 1784.

Truls Lynne Hansen

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Horrebow, Peder Nielsen

Born **Løgstør near Ålborg, Denmark, 14 May 1679**
Died **Copenhagen, Denmark, 15 April 1764**

Peder Horrebow was a proficient and devoted pupil of **Ole Rømer** and spent most of his professional career in the continuation and preservation of Rømer's work.

Horrebow grew up in a poor fisherman's family, and he was not sent to school until the age of 17. His inferior social background made it difficult for him to be accepted in academic circles in Copenhagen, and for most of his life he had recurrent economic difficulties.

In 1711 Horrebow married Anne Margrethe Rossing (*circa* 1690–1749). They had 20 children, of whom 13 lived. Two of their sons, **Christian Horrebow** and Peder Horrebow, Jr. (1728–1812) also became astronomers.

In 1703 Horrebow enrolled in the University of Copenhagen, where soon he became an assistant of the famous astronomer Ole Rømer, lived in his house, and acquired a thorough knowledge of Rømer's astronomical work. Unfortunately, due to financial problems, Horrebow was in 1707 forced to take up a position as teacher in Jutland. Returning to Copenhagen in 1711, where Rømer had died a year before, Horrebow had to work as a clerk at the customs house for his living. Eventually, in 1714, he was appointed professor of astronomy and director of the Copenhagen Observatory. His master's degree was completed in 1716, and in 1725 he obtained a doctor's degree in medicine. He often practiced as a physician to support his large family.

Horrebow was a member of the science academies in Paris, Berlin, and Copenhagen, but he never studied abroad and seems to have traveled very little. In 1753 he retired from his position as director of the Copenhagen Observatory and was succeeded by his son Christian.

The publications of Rømer are quite fragmentary, and our major source of knowledge of him as an astronomer is the works of Horrebow. Horrebow restored or rebuilt Rømer's meridian circle and other instruments at the Round Tower of Copenhagen, and carried on Rømer's work on a comprehensive stellar catalog. The observations of Rømer and Horrebow with the meridian circle represent a considerable step forward in positional astronomy. So also do Horrebow's efforts to properly correct the observation for instrumental errors. In fact, **Tobias Meyer**'s correction formula of 1756 was anticipated by Horrebow.

Horrebow's ultimate goal was to measure stellar parallaxes and thereby demonstrate the correctness of the Copernican model of the Solar System. In 1727 he published a small book wherein he claimed the goal was reached. However, his results soon proved faulty because of inaccurate clocks and the lack of correction for aberration. Such a public fiasco of course made the fisherman's son an easy target for the satiric tongues of academia. Horrebow was an adherent of **René Descartes**'s vortices model of the Solar System; he thus was among those of the time who did not accept **Isaac Newton**'s gravity as the key to the motion of the planets.

The name of Horrebow still lives in the so called Horrebow–Talcott method to determine astronomical latitude. The method was originally developed by Horrebow, forgotten, and reinvented by Talcott in 1883. The idea behind it is to measure transits of two stars with known declinations, one culminating south of the zenith and the other close to the same distance north of the zenith, thus eliminating much of the instrument errors in the calculation of the zenith distance of the celestial pole.

The great fire of Copenhagen in 1728 was a devastating blow to Horrebow: All the instruments in the Round Tower and most of the observational records made by himself as well as Rømer were destroyed. The observatory was out of operation until 1741. Horrebow was, however, never able to resume observational work.

Truls Lynne Hansen

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Horrocks, [Horrox] Jeremiah

Born **Toxteth Park near Liverpool, England, *circa* 1619**
Died **Toxteth Park near Liverpool, England, 3 January 1641**

In addition to being the first person to accurately predict and observe a transit of the planet Venus, Jeremiah Horrocks also discovered the inequalities in the motions of Jupiter and Saturn, and improved upon **Johannes Kepler**'s lunar theory to such an extent that it could not be further improved upon for over a century. It is believed that when Sir **Isaac Newton** stated he had stood on the shoulders of giants, he had Horrocks in mind.

Very little is known about Horrocks's early years. His family was of modest origin; his father William Horrocks was a farmer while his mother, Mary Aspinwall, was the daughter of a well-established family in Toxteth Park. After an early education by local tutors, Horrocks enrolled at Emmanuel College, Cambridge, before reaching the age of 14. As a sizar, he earned his tuition fees and living expenses by serving as the servant of a wealthier student. Horrocks devoured classical literature, often reading the Latin authors in order to become more familiar with the language. He was unable, however, to pursue formal studies in the subjects that most interested him, namely, mathematics and astronomy. Thus, after 3 years at Cambridge, Horrocks left without attaining a degree. It was not an uncommon departure for students with limited means as the university required additional cash payments to qualify for a degree. Horrocks no doubt felt he had learned all that was of interest to him in Cambridge, and returned to Toxteth Park. In the summer of 1639, he accepted employment with the most prominent family in the village of Hoole, possibly as a tutor. Horrocks returned to Toxteth Park after about a year in Hoole. In the 19th century it became common to refer to Horrocks as a clergyman, but available evidence argues against his ever having been ordained.

The study of astronomy preoccupied Horrocks after he left Cambridge. Using an astronomical radius he made for himself, Horrocks found that actual planetary positions were substantially different than what could be projected based on **Philip von Lansbergen**'s *Tabulae Motuum*. That conclusion was also drawn by **William Crabtree**, with whom Horrocks became acquainted through a mutual friend, **John Wallis**, whom Horrocks met at Cambridge. Crabtree introduced Horrocks to the *Tabulae Rudolphinae* and other works of Kepler. Although they never met – Horrocks died the day before they had planned to meet for the first time – Horrocks and Crabtree became very close friends through their correspondence. Their observations indicated the superiority of Kepler's tables in comparison to Lansbergen's, but still found Kepler to be in error. The two young astronomers agreed that thereafter their work would be based strictly on their own observations and not on tables prepared by someone else. Horrocks undertook to correct Kepler's Rudolphine Tables of the motions of the Sun, Moon, and the planets.

One of Horrocks's early projects in this effort was to measure the apparent diameter of the Sun on a regular basis throughout the year. His observations were accurate enough to show that the apparent solar diameter varied exactly as would be expected if the orbit of the Earth was an ellipse with the Sun at one focus. On the basis of these observations, Horrocks developed a more accurate theory of the apparent annual motion of the Sun than those of all his predecessors. Horrocks also attempted to extend this methodology to the apparent diameters of the planets and the Moon, but his results were compromised by the character of his measuring devices.

Detailed observation of the planets also proved rewarding for Horrocks as he detected the apparent acceleration of Jupiter in its orbit, and the apparent deceleration of Saturn in its orbit as one passed the other. He suspected that these values might be subject to periodic changes, and had he lived long enough he would no doubt have confirmed that hypothesis. It is apparent from these results that Horrocks was a very careful observer, producing valuable results in spite of the rather crude nature of the astronomical radius as a measuring device.

Nothing demonstrates Horrocks's skillful integration of observation and theory better than his prediction and observation of the 1639 transit of Venus. Kepler had predicted transits of both Mercury and Venus for the year 1631. The predicted transit of Mercury, observed by **Pierre Gassendi** at Paris, provided the earliest observational confirmation for Kepler's methodology and is often cited as a turning point in the acceptance of Copernican cosmology. The 1631 transit of Venus was not observed as it began after sunset in Europe. However, Lansbergen had also predicted a Venus transit for 1639. Although Horrocks placed more faith in Kepler, the possibility of a second transit piqued his curiosity. Horrocks took Lansbergen's tables and determined that indeed, Lansbergen was correct: A transit would occur about 3:00 p.m. on 4 December 1639. Using the Rudolphine Tables, Horrocks was able to understand why Kepler predicted that the second transit would pass below the visible disk of the Sun. However, with Horrocks's revised and more accurate version of Kepler's table it was clear that Venus would transit the southern face of the Sun, though well below the position predicted by Lansberg. Horrocks did not have absolute faith in his own calculations, so he began his observations on 3 December. His observations were made following the procedure used by Gassendi: A small telescope projected an image of the Sun on to a white surface in a darkened room. Venus was not detected on 3 December. On 8 December, a Sunday, Horrocks watched the Sun from sunrise until 9:00 a.m. 10:00 a.m. until noon, and 1:00 p.m. until 3:00 p.m. his predetermined time of transit. He was called away at that time, but when he returned at 3:15 and adjusted his telescope, Horrocks was overjoyed to see a sharp round black disk on the projected face of the Sun. Venus had entered the disk of the Sun, and the transit had already proceeded to second contact.

Horrocks watched the transit for about 35 min until the Sun set. During this time, he observed Venus move the distance of about two planetary diameters across the Sun's face. From his observations, Horrocks calculated the diameter of Venus to be about 1/30 the diameter of the Sun. Based on his extensive measurements of the Sun's apparent diameter, the resultant apparent diameter of Venus was 76 ± 4″, much smaller than the traditional value of 180″. Moreover, on the basis of this observation, Horrocks proposed a value of the horizontal solar parallax of only 14″, substantially lower than any previous value, for example, **Tycho Brahe**'s 180″, Kepler's 59″, or **Johannes Hevel**'s 40″. (The last figure was published a generation after Horrocks.)

Horrocks's discovery of the possible transit of Venus only a month before it was predicted to occur left him little time to alert the broader scientific community, but it seems likely that he also had too little confidence in the accuracy of his methods to do so. He wrote to his brother in Manchester and to Crabtree, both of whom he believed might enjoy the experience of observing the transit. His brother was clouded out; so the only person who would confirm Horrocks's observation was Crabtree. Although the Sun was obscured by clouds for most of the period of the transit, it appeared suddenly at 3:35, and Crabtree was able to prepare a sketch that confirmed Horrocks's smaller figure for the apparent diameter of Venus.

Horrocks's description of his observation of the transit of Venus, his analysis of his results, and their significance were drafted as *Venus in Sole Visa* before his death. The manuscript was eventually transmitted to Danzig by **Christiaan Huygens** and was published posthumously in 1662 by Hevel as the first chapter of the latter's self-published book on the transit of Mercury, titled *Mercuris in Sole Visus*.

Horrocks's other substantial achievement was in his development of a new lunar theory, which he discussed in letters to Crabtree and **William Gascoigne**. Horrocks's major discovery was that the line of apsides for the lunar orbit oscillates periodically and the orbital eccentricity varies over time. His ability to account for these effects produced a lunar theory that was superior to that of Kepler. **John Flamsteed** showed that Horrocks's lunar theory reduced errors to only 2′ compared to 15′ errors in the best of previous theories. Newton learned of Horrocks's theory when he received a copy of Horrocks's *Opera Posthuma* in 1672. Although Newton attempted to improve the theory, he was unsuccessful. It was not until **Tobias Mayer** published his initial lunar theory in 1753 that any improvement over Horrocks's theory was achieved. Substantive improvement of lunar theory would have to wait until the introduction of perturbation theory and the substitution of Leibnizian calculus for conventional geometry by **Leonhard Euler**, **Pierre de Laplace**, and **Joseph Lagrange**.

Francine Jackson

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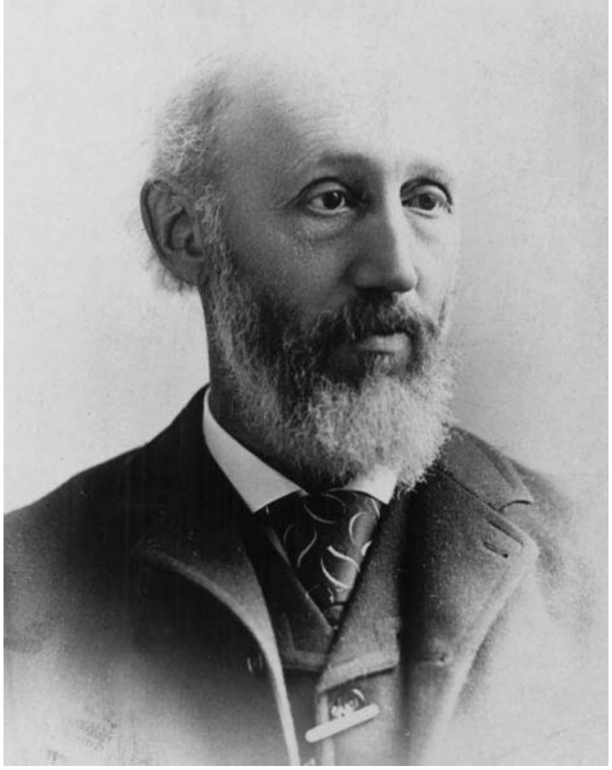
Hough, George Washington

Born **Tribes Hill, New York, USA, 24 October 1836**
Died **Evanston, Illinois, USA, 1 January 1909**

George Hough, American astronomer and meteorologist, was the first to determine the duration of Baily's phase of a solar eclipse (caused by the Sun shining between mountains on the Moon) using



a chronograph of his own invention during the eclipse of 7 August 1869. He also discovered and determined coordinates of a number of double stars.

Hough was the son of William and Magdalene (*née* Selmser). Hough ancestors were early German immigrants who settled in Montgomery and Fulton Counties, New York. George attended school at Waterloo and Seneca Falls, New York, and graduated from Schenectady's Union College in 1856 with high honors. He worked as principal of a public school in Dubuque, Iowa, for 2 years, after which he undertook a year of graduate work in mathematics and engineering at Harvard University.

In 1859 Hough was appointed assistant astronomer to director **Ormbsy Mitchel** at the Cincinnati Observatory. He later accompanied Mitchel to Albany, New York and worked as his assistant. Upon Mitchel's death in 1862, Hough became acting director of the Dudley Observatory and was elected director in 1865. He devoted his time between 1862 and 1874 to astronomical and meteorological research and invented instruments including a recording chronograph. In 1869 the Dudley Observatory sent an expedition led by Hough to observe the solar eclipse at Mattoon, Illinois. Hough and **Lewis Swift** used the new recording chronograph during the eclipse of 7 August 1869 to confirm the phenomenon of Baily's beads (first described by **Francis Baily**) and accurately recorded the duration of the occurrence for the first time.

In 1870 Hough married Emma C. Shear, the daughter of Jacob H. Shear. They had two sons, George Jacob and William Augustus.

In 1873 the trustees of the Dudley Observatory resolved to terminate the salaries of its officers and employees as a result of which Hough resigned his position as director. He moved to Chicago ometime between 1874 and 1878 and was engaged in the business of making scientific instruments in Riverside, Illinois. In 1879 he was appointed professor of astronomy at the University of Chicago and director of the Dearborn Observatory. However, neither the Chicago Astronomical Society that had founded the Dearborn Observatory nor the University of Chicago could pay Hough an appropriate or regular salary until 1881. Hough made good use of the observatory's telescope, a 18½-in. refractor built by Alvan Clark & Sons, one of the largest in the world when it was first installed in 1866. Using this excellent instrument he observed double stars and began a methodical visual observation of the planets focusing particularly on Jupiter.

In 1887 the affairs of the University of Chicago reached a financial crisis, and the directors of the society realized that they would have to resort to other measures to establish the continuance of the observatory. The Chicago Astronomical Society and Northwestern University entered into an agreement on 29 October 1887 to reestablish the Dearborn Observatory at Northwestern University in Evanston, Illinois.

Hough planned and supervised the move to the Northwestern University campus and designed the great dome for the new Dearborn Observatory incorporating many new and original features. He continued as director of the observatory and became professor of astronomy at the university.

At the Dearborn Observatory Hough became passionately involved with the discovery of close double stars. He discovered and measured 627 double stars and prepared a catalog of 209 for publication. He also began to study Jupiter extensively, carefully observing its surface details, and became a world renowned expert on that planet. Hough's Jovian discoveries included information on the dependence of rotation rate on latitude and on possible time-dependence of the size of the Great Red Spot. His obsession with Jupiter continued for the rest of his life and earned him the nickname "Jupiter."

Apart from being involved with physical observations of the planets, their satellites, and comets, Hough was also a prolific inventor of meteorological instruments. His inventions included a star charting machine (1862), an automatic recording and printing barometer (1865), a printing chronograph (1871), and also a recording chronograph (1879). Hough's inventions also included a "meteorograph" in which he combined a barometer and wet- and dry-bulb thermometers, a photographic sensitometer, an equatorial revolving dome, and an electric control for the equatorial driving clock. Another important invention was Hough's automatic anemometer for recording the direction and speed of wind. He also invented a special observing seat that the astronomer could easily manipulate to remain comfortable at the eyepiece of the long-focus telescope. This observing seat, which was both practical and convenient, was accepted by important observatories in the United States. The instruments Hough invented won him many awards; two of the most distinguished ones he received were at the Centennial Exposition in Philadelphia in 1876 and the Chicago World's Fair in 1893.

Hough was affiliated with many important scientific societies of his time and held in high esteem by his peers. He was elected foreign associate of the Royal Astronomical Society in London in 1903. He was also an honorary member of the Astronomische Gesellschaft in Leipzig. He was nominated president of the World

Congress on Astronomy and Astrophysics, held in connection with the 1893 World Columbian Exposition in Saint Louis, also known as the World's Fair.

Hough led a creative, active life to the very end and served as director, astronomer, and professor until his death. Hough's numerous papers and research articles were published in various scientific journals and in transactions of learned societies both in America and abroad. Hough describes many of the instruments invented by him in Volume I and II of the *Annals of Dudley Observatory* (1866–1871). He gives an account of the solar expedition of 1869 in *Annals of Dudley Observatory*, 2 (1871): 296–323. He published the *Annual Reports of Dearborn Observatory* (Chicago, 1880–1886) and the *Annual Reports of The Chicago Astronomical Society* (1880–1887).

Hough's observations of double stars were published as "Catalogue of 209 New Double Stars" in the *Astonomische Nachrichten*, 116 (1887): 273–304. Of Hough's many other publications, the most noteworthy are "Our Present Knowledge of the Condition of the Surface of Jupiter," *Popular Astronomy* 13 (1905): 19–30, "Jovian Phenomena," *Astrophysical Journal* 6 (1897): 443–446, "Observations of the Planet Jupiter, Made at the Dearborn Observatory," *Monthly Notices of the Royal Astronomical Society* 60 (1900): 546–565, and "Observing Seat for Equatorial," *Sidereal Messenger* 1 (1883): 23–26.

Suhasini Kumar

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Hough, Sydney Samuel

Born **London, England, 11 June 1870**
Died **Gerrard's Cross, Buckinghamshire, England, 8 July 1923**

Sydney Hough followed **David Gill** as Astronomer Royal, Cape Town, South Africa. He oversaw significant progress on the Cape Astrographic Catalog.

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Houtermans, Friedrich Georg

Born **Zoppot near Danzig, (Gdańsk, Poland), 22 January 1903**
Died **Bern, Switzerland, 1 March 1966**

German experimental physicist Friedrich (Fritz) Houtermans is known within astronomy almost exclusively for a single theoretical idea, that it should be possible to build helium from hydrogen in stars and so provide stellar energy *via* a catalytic cycle using some heavier elements. His colleague in this endeavor was the somewhat younger British astrophysicist **Robert Atkinson**.

Houtermans was raised in Vienna (and frequently taken to be a native) by his mother, Elsa Houtermans, the first woman in Vienna to earn a doctorate in chemistry. He began physics studies at Göttingen in 1921, receiving his Ph.D. in 1927 for work with James Franck on resonant fluorescence in mercury. **George Gamow** arrived in Göttingen the next year, and they collaborated on an extension of Gamow's theory of alpha decay of elements like uranium and thorium, which involved quantum mechanical tunneling or barrier penetration. In 1929 Atkinson (then visiting Göttingen) and Houtermans turned Gamow's idea around and considered tunneling as a way of assembling complex atoms, thereby arriving at much of the essence of the proton–proton chain put forward in 1939 by **Hans Bethe** (Nobel Prize 1967 for this work). They suffered from lack of knowledge of the neutron (discovered in 1932), which required them to get electrons as well as protons into their nuclei. Gamow, Atkinson (who had been the student of **Arthur Eddington**), and Houtermans dubbed the process a thermo-nuclear reaction.

Houtermans took his Dr. Hab. degree at the Technische Hochschule, Berlin, in 1927 working with Gustav Hertz on electron microscopy. In 1930, he married Charlotte Riefenstahl, who had also earned a 1927 Ph.D. in physics from Göttingen. Having one Jewish grandparent, in 1933 Houtermans thought it wise to leave and took a position at the electrical and musical instruments company HMV in England. While there, he attempted to verify an implication of **Albert Einstein**'s A and B coefficients that a light beam passing through a medium with an inversion of level populations would be amplified. But, instead of discovering the laser 20 years early, he burned out an amplifier.

Not finding England congenial, Houtermans moved to Kharkov University in the Soviet Union in 1934, working initially on neutron captures in boron, silver, and cadmium. His life for the next 11 years nearly defies description, involving imprisonment in both the USSR and Nazi Germany, and work at a private laboratory in Germany for several years (during which he made an estimate of the critical mass of uranium-235 and of element 94, which he did not yet know was called plutonium, required for run-away fission and also for a fission bomb). Houtermans was also part of a group of German scientists who visited occupied Kharkov in 1941 in an attempt to discover what had been learned there about an assortment of war-related parts of physics.

Houtermans returned to Göttingen and a position at the Physikalische Institut in 1948, and accepted a professorship at the University of Bern, Switzerland, in 1952, where he worked until his death, primarily on natural radioactivities and their applications to geophysics and meteoritics. He and Charlotte chose to be remarried in

1953 as a result of their wartime experiences, which had included prolonged separation.

Michael Meo

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Houzeau de Lehaie, Jean-Charles-Hippolyte-Joseph

Born **Mons, (Belgium), 7 October 1820**
Died **Schaerbeek near Brussels, Belgium, 12 July 1888**

The Belgian astronomer Jean-Charles Houzeau served astronomy in a number of ways, including as director of the Royal Belgian Observatory, but is best known for his extensive bibliography of astronomy.

Born to a rich, old family of nobility, Houzeau's ancestors added the sobriquet "de Lehaie" to distinguish their branch of the family. As a convinced democrat, Houzeau never used his full, aristocratic name; he called himself simply Houzeau. He was educated at home in his father's extensive library, and showed a brilliant intelligence and a spirit of inquiry, but also a love of freedom and independence. His family routinely spent winters in Paris, France, where the young Houzeau spent most of his time in the Bibliothèque Nationale recording data on all subjects of interest to him. He usually lived at the Sorbonne with his uncle, the vice rector of the University of Paris.

After a successful period at the Collège de Mons, Houzeau intended to study science at the Free University of Brussels, but in 1837 he failed his first examinations. Houzeau continued to study at the mining school in Mons as an independent student and read extensively in the Belgian National Library. While living with his parents in Mons, in 1848 Houzeau built his own observatory, constructing an equatorial telescope with lenses purchased in Paris and a wall quadrant. At the same time, Houzeau wrote on science, technology, and politics in local newspapers; in 1839 he published a well-regarded book about turbines. Houzeau spent 1840 and 1841 in Paris where he attended lectures in science, politics, and social studies at the University of Paris.

Houzeau was still unknown among astronomers in 1844 when he published a paper on the Zodiacal Light in the *Astronomische Nachrichten*. That paper was followed some months later by a remarkable paper in the same journal on the aberration of light in observation of double stars with a detectable proper motion, a paper praised by **John Herschel**, **Charles Smyth**, and others. Both papers were published on the recommendation of **Lambert Quetelet**, then director of the Royal Observatory in Brussels. Quetelet invited Houzeau to work at the Royal Observatory as an unpaid volunteer in 1845. At the observatory, Houzeau made many observations and calculations of the orbits of planets and a comet. On the basis of his performance as a volunteer, he was employed as an assistant astronomer at the observatory in 1846.

Unfortunately, because of his leftist political opinions and activities, only 3 years later, over strong objections by Quetelet, Houzeau was dismissed from his job by the Belgian government in the wake of the unrest of 1848. Houzeau had been observed leading a democratic meeting, and barely escaped when the meeting was interrupted by royalists. After travels in Germany and Switzerland, in 1850 Houzeau settled in Paris where he continued to read and record notes about everything for 5 years. Houzeau then returned to Belgium providing astronomical support for military surveying of the Belgium coast, but the government support for the work was withdrawn after 2 years. During this period, he continued to publish prolifically on astronomy, geology, history, and meteorology. In 1856, Houzeau was elected full member of the Royal Academy of Belgium.

Responding to a long felt desire, in 1857 Houzeau traveled to the United States, landing in New Orleans, Louisiana. Though he expected to remain only a few months, his visit extended to 20 years. He became a surveyor and farmer near San Antonio, Texas, and traveled extensively in southern and western Texas while studying nature and the sky. When the Civil War broke out he refused any involvement with the Confederate cause; instead, he assisted the leaders of the anti-slavery movement and underground railway for slaves until forced to flee to Mexico. After nearly a year in Matamoros, Mexico, when word came that Union troops had taken control of New Orleans, Houzeau returned to the city and worked as reporter for the radical anti-slavery French language newspaper, *l'Union*, and then became the managing editor of the *New Orleans Tribune*, which replaced *l'Union* in 1864. Houzeau received frequent death threats for his editorial stands taken in the *Tribune* and other efforts on behalf of the African Americans in New Orleans.

In 1867 Houzeau left the United States to settle as a planter at Ross View, in the Blue Mountains of Jamaica. There, he operated a banana and coffee plantation and adopted two black boys. His social instincts continued to function actively as he founded a school for blacks, but he also took more time for astronomical observations. While continuing to send papers to the Royal Academy of Belgium, Houzeau created an authoritative map and catalog for all stars visible to the naked eye in the northern and southern skies. In order to complete this map, he made a journey to Peru *via* Panama. During the several months Houzeau spent in Panama he contracted a tropical disease that would eventually prove fatal. Impressed with the effect of transparent, steady air at Jamaica and in Peru on the visibility of faint stars and the Zodiacal light, Houzeau speculated prophetically that in the future astronomical observatories would be built on mountaintops in dry climates.

In 1876 Houzeau was called back to Belgium to succeed Quetelet as director of the Royal Observatory. Although many scientists supported him for the position, the conservative government hesitated for 2 years after Quetelet's death before the Belgian king forced Houzeau's appointment upon them. As the observatory director, Houzeau greatly modernized the facility and its instruments. He created a spectroscopy section, trebled the staff, and made a clear distinction between astronomical and meteorological research, a difference that was not always clearly understood by the government. Because of these advances, the observatory building in Brussels was clearly too small. Houzeau proposed relocation of the observatory to its current site in Uccle, south of Brussels. His proposal was accepted, but the construction was not completed until after his death.

As the Royal Observatory director, Houzeau went back to Jamaica to observe the solar eclipse of 1878. Houzeau's return to

Belgium was complete by then in that he was honored with the Belgian Royal Academy's prestigious Five Year Award, and elected president of both the Royal Academy and the Belgian Geophysical Society.

In 1883 Houzeau again visited San Antonio to observe the transit of Venus, but the results where disappointing. Shortly after his return from this last journey, he resigned as director of the observatory, because of his bad health and his disappointment regarding the lack of progress in the construction of the new observatory in Uccle. Nevertheless, Houzeau continued his scientific work until a few months before his death.

Houzeau is best known for his *Bibliographie générale de l'astronomie*, a prodigious compilation of all astronomical publications and manuscripts from Antiquity to 1880, for which he had collected data since his youth. Houzeau's partner in this enormous effort was Albert Benoît Marie Lancaster (1849–1908), astronomer and librarian at the Royal Observatory. Only two of their three planned volumes were ever published; these appeared in five sections published between 1880 and 1889. The first volume completed was Volume II, the second section of which appeared in 1882. Volume I was completed in three sections, the last of which appeared in 1889 after Houzeau's death. Lancaster saw the final sections of Volume I through publication, but the death of Houzeau was a blow to his own resolve and he never attempted to complete the third volume.

In spite of Houzeau's desires to the contrary, in 1890, the city of Mons erected a monument to commemorate him.

Tim Trachet

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Hoyle, Fred

Born **Bingley, West Yorkshire, England, 24 June 1915**
Died **Bournemouth, Dorset, England, 20 August 2001**

Fred Hoyle applied field theory to cosmology (including a new matter-creation field), proposed an alternative theory of gravitation, and developed time-symmetric electrodynamics. He was thereby an intellectual link, stretching from the theories of **Albert Einstein** and **Paul Dirac**, toward modern cosmological theories. A national figure, he was knighted in 1972 for a number of distinguished contributions to astronomy and to the United Kingdom – Hoyle had worked on radar during World War II, founded Cambridge's Institute of Theoretical Astronomy, and chaired the Science Research Council's advisory committee for the Anglo–Australian Telescope. His name became well known to the public following his British Broadcasting Company broadcasts in 1950. Hoyle's 1955 book, *Frontiers of Astronomy*, inspired both astronomers and the public.

Hoyle grew up in industrial western Yorkshire. In his autobiography, he eloquently describes his early "war" with the educational system in Gilstead, a village near Bingley. His family was far removed from the privileged classes that gave England so many noted scientists. His mother had worked in the Bingley textile mill but later studied music at the Royal Academy and became a professional singer before she married. At age nine, Hoyle quit school after being slapped by a teacher. His mother strongly supported him in the confrontation with local authorities. Hoyle eventually won a scholarship to the Bingley Grammar School, to and from which he walked 4 miles daily. From there, he gathered financial support to enter Cambridge University's Pembroke College in 1933. At Pembroke, he won a half share of the Mayhew Prize in the mathematical *tripos*. Later, he became Dirac's research student because, as Hoyle put it, Dirac could not resist the circular logic of a supervisor who did not want a research student who did not want a supervisor!

Perhaps Hoyle's most successful theory was that of nucleosynthesis in stars. In 1946, he showed that the interiors of massive, evolved stars reached very high temperatures and densities. Under those conditions, the natural dominance of iron in the middle-mass abundance peak could be understood as a consequence of statistical equilibrium. Hoyle and later collaborators called this the "e-process," where "e" stood for "equilibrium." If explosive disruption of the star followed, then the interstellar medium would be enriched with iron. This important result shifted attention toward nucleosynthesis in the stars and created the field of galactic chemical evolution.

In 1954, Hoyle detailed not only the "e-process," but also the synthesis of all elements between carbon and nickel as a series of successive stages in which the ashes of one reaction became the fuel for the next. Much of that conceptual structure survives intact today. By the late 1960s, radioactive nickel was demonstrated (by others) to be the parent of iron, was demonstrated to be the radioactive power source for a supernova's light curve, and served as a test of the theory by the detection of its gamma rays.

Hoyle is perhaps most widely known as the creator of the steady-state theory of the Universe, although Hermann Bondi and Thomas Gold also published a discussion of this idea from a more philosophical viewpoint. Hoyle's approach, however, went straight to the need for an alternate theory of gravitation that included a field for the creation of matter. Hoyle thus introduced a scalar field for that purpose. Many of his publications, coauthored with Jayant V. Narlikar over the next 15 years, explored the mathematical implications of this (and other) fields in cosmology. Hoyle's time-symmetric quantum electrodynamics was a Herculean effort of theoretical physics, one that was seen as capable of supporting the steady-state theory. These concepts established Hoyle as champion of the concept of continuous creation of matter in the Universe, and the field equations that achieved this result will remain associated with his name. Hoyle's field equations led to an exponentially expanding but spatially flat metric that reappeared in similar guise within the inflationary theory of big-bang cosmology. Philosophical beauty was not Hoyle's only guide, however. From the work of **Victor Ambartsumian** and others, Hoyle became convinced that high-energy astrophysical processes represented the ejection, rather than the infall, of matter around extremely massive objects.

Hoyle's indignation at premature attacks on the steady-state theory placed him in the position of seeming to be a sore loser in the scientific debate with Big-Bang proponents – a perception that lasted until his death. But in 1964, Hoyle and Roger J. Taylor pioneered nucleosynthesis calculations in either a Big Bang or series of lesser cosmic explosions that emphasized an elevated cosmic abundance of helium. In 1967, with Robert V. Wagoner and **William Fowler**, Hoyle demonstrated that both isotopes of hydrogen and both isotopes of helium, as well as lithium-7, could be made during the Big Bang. These calculations set the standards for Big-Bang nucleosynthesis. Nonetheless, the common image of Hoyle is of his giving the Big Bang its name in sarcasm. Following accurate measurements of the cosmic microwave background radiation, Hoyle acknowledged its possible knockout blow to the simple steady-state model. His monograph, *A Different Approach to Cosmology* (2000), coauthored with Geoffrey R. Burbidge and Narlikar, presented an alternative to the Big Bang, by employing an oscillating and expanding steady-state Universe.

Hoyle was also a pioneer in computational stellar evolution, specifically physical models of stars becoming red giants and of their exploding as supernovae. In 1953, Hoyle and **Martin Schwarzschild** constructed numerical models of the evolution of stars beyond the main sequence that not only explained the physical nature of red giant stars but also introduced many physical ideas that now seem as if they must always have been known. The dimensionless variables q, t, and p that Schwarzschild later used in his book on stellar evolution were all integrated by hand! Innovations included an isothermal helium core, a thin hydrogen-burning shell ("burning" on the C–N cycle), and a deepening surface convection zone owing to failure of the zero boundary condition at the surface. These assumptions are now taken for granted.

When Hoyle first visited the Kellogg Radiation Laboratory at the California Institute of Technology in 1953, he argued that the triple-alpha process would be inadequate for both red giants and nucleosynthesis unless carbon-12 were to have an excited state with zero spin and positive parity at 7.7 MeV excitation. Initially, this pronouncement was viewed with incredulity, because carbon-12 has very few excited states, but was soon shown to be precisely true. Hoyle's prediction of this energy state was the most accurate that had ever been achieved, and it had relied on astrophysics rather than nuclear physics! He argued that this excited state of carbon-12 must exist, because we ourselves are here – an anticipation of the anthropic principle.

In 1960 and 1964, Hoyle and Fowler published physical interpretations of the spectroscopically defined supernovae of Types I and II. They argued that Type Is were the explosions of degenerate white dwarfs, whereas Type IIs were implosion–explosion sequences occurring within massive stars. Today, these are our paradigms, although Hoyle and Fowler did not anticipate the role of neutrino transport in the Type II rebound, but argued that centrifugal barriers prevented further collapse and allowed the star's thermonuclear power to eject matter.

Hoyle's controversial ideas about interstellar biology began in collaboration with Cambridge student Nalin C. Wickramasinghe, who studied the condensation of refractory dust in both the winds emitted by carbon stars and within the interiors of supernovae. A new field of investigation was later envisioned by others if such isotopically anomalous stardust could be found within meteorites. The first such stardust in meteorites was isolated in 1987 and has enormously enriched astronomical knowledge. Hoyle's detour into interstellar biology grew from recognition that the absorption spectra of bacteria resembled that of interstellar dust, together with his conviction that some dominant mechanism was necessary to process interstellar matter into such forms with high efficiency. For this, Hoyle and Wickramasinghe boldly suggested reproductive chemistry. When that idea was attacked by biologists' public comments rather than through published scientific arguments, Hoyle's back stiffened. He thereafter pitched his books directly to the public rather than to scientists.

Hoyle had written imaginatively for the public in his novel, *The Black Cloud* (1957), in which he postulated that cold molecular clouds developed nervous systems and a consciousness that controlled their environments. The physical notion stayed with him. Writing primarily for the public, Hoyle and Wickramasinghe argued in *Lifecloud* (1978), *Diseases from Space* (1979), and *Space Travelers: The Origins of Life* (1980), that comets carried the basic chemicals of DNA replication, and even of influenza epidemics. The scorn of the biochemical world was total. It must be added, however, that the role of comets in delivering biochemically sensitive materials remains an open topic, as is the question of whether life emerged first on Earth or another planetary body. Many felt that Hoyle might have shared the 1983 Nobel Prize in Physics (awarded to Fowler and **Subramanyan Chandrasekhar**), but for Hoyle's embarrassed status over exobiology.

Much of Hoyle's life was spent bucking the establishment and playing devil's advocate against conventional wisdom – traits that seem further reflections of his upbringing and childhood "war" with the Yorkshire educational system.

Donald D. Clayton

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Hubble, Edwin Powell

Born **Marshfield, Missouri, USA, 20 November 1889**
Died **San Marino, California, USA, 29 September 1953**

American extragalactic observer Edwin Hubble provided the first persuasive observational evidence that the Universe is expanding and gave his name to the constant, H_0, which describes the rate of that expansion, and its reciprocal, the Hubble time. He also convinced his contemporaries of the reality of external galaxies or "island universes" by discovering known kinds of variable stars in them and devised a classification system for galaxies that is still used.

Hubble, the fifth of seven sons and a daughter of John Powell Hubble and Virginia Lee James, received a BS degree for study of mathematics and astronomy from the University of Chicago in 1910 and continued on to Queen's College, Oxford, England. As a Rhodes Scholar, he studied Spanish and law, receiving a BA in jurisprudence in 1912. Returning to the United States, he taught Spanish and coached basketball at New Albany High School in Indiana, before going back to the University of Chicago in 1914 for graduate work in astronomy. Hubble completed a thesis on photographic investigations of faint nebulae with **Edwin Frost** in 1917, hurrying through the writing and defense so he could volunteer for service with the United States infantry. He was posted to France, returning in 1919 with the rank of major, though Hubble was apparently never under fire, to take up the position at Mount Wilson Observatory that had been offered to him by **George Hale** before the United States entered World War I. In 1924, Hubble married Grace Leib Burke, the widowed daughter of a Los Angeles banker. She died in 1981; they had no children.

At Mount Wilson Observatory, Hubble used the 60-in. telescope to conclude in 1922 that a number of diffuse emission nebulae in the plane of the Milky Way were reflecting light from stars embedded in them. Then, with the 100-in. Hooker telescope, he began looking for familiar kinds of stars in bright nebulae outside the plane of the Galaxy. In the fall of 1923, Hubble thought he had spotted a nova in M31, the Andromeda Nebula, but soon concluded that it was a Cepheid variable, whose pulsation period would tell him the distance to the nebula. After finding a few more Cepheids there, he concluded that Andromeda was well outside any possible confines of the Milky Way, and so constituted a separate star system. This was announced in a paper read for him by **Henry Norris Russell** at a joint meeting of the American Association for the Advancement of Science and the American Astronomical Society on 1 January 1925. The discovery of Cepheids in M31, and, soon after, NGC 6822 and M33, was generally regarded by the astronomical community as a definitive answer to the question of whether other galaxies existed, as had been debated by **Heber Curtis** and **Harlow Shapley** in 1920 before the United States National Academy of Science.

In the mid-1920s, Hubble concentrated on classification of what he continued to call extragalactic nebulae (galaxies) in terms of their shapes and colors. He set aside an assortment of "irregular" looking nebulae and classified the "regular" ones into a sequence of ellipticals (of increasing ellipticity), branching into two sequences of spirals (with and without bars) of increasingly conspicuous arms. The system was put forward as an empirical classification, but subclassification into "early" and "late" types suggested an evolutionary scheme like the one proposed by **James Jeans** on theoretical grounds, in which contraction and spin-up would gradually turn round shapes into flattened ones. Indeed, the Hubble classes were perceived as too much motivated by evolutionary considerations to be adopted as a standard at the 1928 general assembly of the International Astronomical Union [IAU] in Rome, which Hubble attended, but have since become the norm, subject to further refinements.

By 1928, the community was also aware of a number of rather large, positive, radial velocities that had been found for spiral nebulae over the past 15 years by **Vesto Slipher** and of solutions to the equations of general relativity found by **Albert Einstein** and by **Willem de Sitter**. Einstein's solution was static, with gravitation balanced by a cosmological constant. De Sitter's solution had no matter, but test particles could be expected to show redshifts, correlated with their distances. **Ludwig Silberstein** had said that the correlation should be a quadratic one, and this had guided **Knut Lundmark** and several other astronomers in the 1920s to look at the data. The correct correlation was later shown by **Hermann Weyl** to be linear. Generally unknown at the time were expanding, nonempty solutions to the Einstein equations that had been formulated by **Alexander Friedmann** (1922), **George Lemaîtres** (1927), and **Howard Robertson** (1928).

Returning home from Rome, where he had been elected president of the IAU Commission on nebulae in succession to Slipher, Hubble settled down to get the most accurate possible relative distances for nebula from his Cepheids, other bright stars, and even the brightnesses of whole nebulae, and to correlate those distances with Slipher's redshifts (positive velocities).

Hubble's 1929 paper, which was accompanied by one by **Milton Humason** reporting a velocity larger than any of Slipher's, is generally regarded as marking the discovery of the expansion of the Universe. Hubble found a slope to the linear velocity–distance correlation of about 536 km/s/Mpc, later adjusting this up and down to 550 and 526 km/s/Mpc. The implied Hubble time (approximate age of an expanding Universe) was about 2 billion years, close to ages being found for the Earth and for some stars at about the same time. Hubble never firmly endorsed the expansion interpretation, partly because some of his later work on numbers of galaxies versus their apparent brightnesses seemed to be inconsistent with that interpretation, and he wrote at times of a possible "unknown law of nature" for the redshifts. Over the next decade, Humason measured ever-larger redshifts and Hubble found ever-larger distances, continuing to support a linear correlation and a value of H near 500 km/s/Mpc.

Hubble also attempted to measure total brightnesses of distant nebulae versus their redshifts and to count them as a function of brightness and distance, still using the 100-in. telescope but hoping for data from the 200-in. being planned and constructed for Palomar Mountain. With the United States entry into World War II, Hubble volunteered again and was put in charge of ballistics and wind tunnels at Aberdeen Proving Ground in Maryland. The 200-in. Hale telescope gradually became operational in 1948/1949, but Hubble (who had also hoped to succeed **Walter Adams** as observatory director) was no longer well enough to be a major user. Humason continued to measure redshifts – his "personal best" was nearly 20% the speed of light – while Hubble turned other aspects of his program over to Allan R. Sandage, a graduate student in astronomy at the California Institute of Technology, who became his scientific heir, and the only person who could claim in any sense to have been Hubble's student. It was left for **Walter Baade** to resolve individual red stars (but not the RR Lyrae variables) in the Andromeda nebula and thereby show that it was about twice as far away as Hubble had found. H_0 was therefore only half as big, and the Hubble time was at least 4 billion years rather than 2 (removing a seeming discrepancy between the age of the Universe and the ages of the objects in it). Curiously, this was also announced in Rome, at the 1952 General Assembly of the IAU, the first held after commissioning of the 200-in telescope.

In addition to the presidency of Commission 28, Hubble at various times also assumed offices in the American Astronomical Society (vice president), the United States National Academy of Science [NAS] (vice president), and the Astronomical Society of the Pacific (president). He received medals and honorary memberships from the NAS, the Royal Astronomical Society (London), the United States government (Medal of Merit for his work in World War II), the Institut de France, the Vienna Academy of Science, and others, and honorary degrees from Princeton University, Brussels University, Occidental College, and the University of California (Berkeley). The Hubble Space Telescope was named for him after its launch and before the discovery of the flaw in the shape of its primary mirror.

Helge Kragh

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Huggins, Margaret Lindsay Murray

Born **Dublin, Ireland, 14 August 1848**
Died **London, England, 24 March 1915**

At the time of her astronomical work with her astronomer husband, Margaret Lindsay Huggins was a woman of wide cultural interests that included music and art, and already had a competent knowledge of astronomy, kindled in childhood by her grandfather.

Margaret Lindsay (*née* Murray) Huggins was born in Dublin, the daughter of John Majoribanks Murray, solicitor, and his first wife Helen Lindsay who were both Scottish. Apart from some years in a boarding school in England, she lived in Dublin until her marriage at the age of 27 to the 51-year-old **William Huggins** in 1875.

In spite of the discrepancy in their ages, the Huggins partnership was a happy and successful one. They began their scientific collaboration by pioneering the use of the dry gelatin photographic plate for astronomical spectroscopy, producing first-class spectra of stars, planets, and comets. Other objects of special study were the Orion Nebula and Nova Aurigae (1892). Between 1903 and 1905 the couple turned to laboratory spectroscopy and published a series of four papers on the spectrum of radium.

Margaret's name does not appear as coauthor on their published work until 1889, possibly by her own wish, but there is ample evidence that she was in fact a collaborator on equal terms with her husband from the beginning, an excellent visual observer, and an extremely hard worker. Marie Curie compared Margaret's position with her own as a partner in a scientific marriage.

Margaret Huggins's contribution to astronomy was recognized by the Royal Astronomical Society, then an all-male organization, which elected her, and her close friend, the writer **Agnes Clerke**, honorary members in 1903.

At the end of the Huggins' active lives, Margaret Huggins was responsible for editing and collecting their scientific papers in a handsomely produced volume, illustrated with her own drawings. She later donated their observing notebooks and other items from Tulse Hill to Wellesley Women's College in the United States.

Margaret Huggins survived her husband by only 5 years. A memorial plaque in the crypt of Saint Paul's Cathedral, London, commemorates William Huggins, astronomer and Margaret Lindsay Huggins, his wife and fellow-worker.

Mary T. Brück

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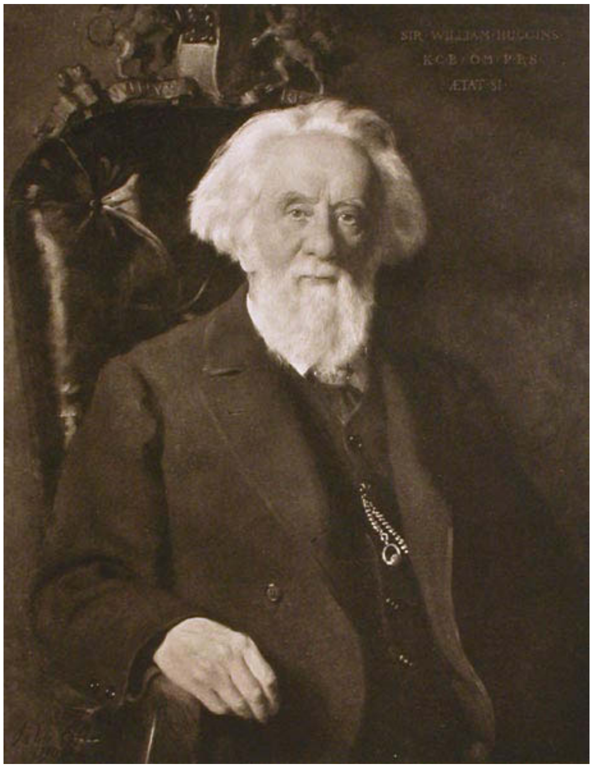
Huggins, William

Born **London, England, 7 February 1824**
Died **London, England, 12 May 1910**



Pioneering spectroscopist Sir William Huggins, the only child of William Huggins, a mercer, had little formal schooling, his education being mainly achieved at home under private tutors. As a young adult he took a keen interest in the sciences, especially microscopy and astronomy, while dutifully assisting in the family business. When his father died, William found that his means, though modest, would allow him to devote himself entirely to his favorite hobby. He sold the family business and bought a house in Tulse Hill, then a suburb of London, where in 1856 he erected an observatory in the garden. It was to be his home and place of work for the rest of his life.

For the first few years Huggins's main activity was observation of the planets, but in 1863, following the interest sparked by the work of the German scientists **Gustav Kirchhoff** and **Robert Bunsen**, he moved into the field in which he made his name, namely, astronomical spectroscopy. He and William Allen Miller (1817–1870), professor of chemistry at Kings College, London and an experienced spectroscopist, combined their talents to produce and observe visually the spectra of some bright stars that they could compare with those of known chemical elements, using a spectroscope attached to the Tulse Hill telescope. They also observed the spectra of planets and comets. While not the very first to enter this new field, their work established them among the pioneers.

Huggins's reputation was greatly enhanced in 1864 when he made the momentous observation that the spectra of certain nebulae consist only of emission lines. Huggins exhibited unusual intuition in speculating that the nebulae were composed not of stars but of glowing gas by applying Kirchhoff's arguments. Still collaborating with Miller, Huggins found that the spectrum of the nova of 1866 (TCvB) in Corona Borealis was also of a gaseous nature. These spectacular discoveries earned for Huggins Fellowship in the Royal Society and its Royal Medal (1866) as well as the Gold Medal of the Royal Astronomical Society, jointly with Miller (1867). In 1869 Huggins introduced the use of the Doppler shift in a star's spectrum as a means of determining its velocity in the line of sight. Though his first result (for Sirius) was grossly inaccurate, the method was right, and opened up an entirely new field of astrophysics.

Huggins's career advanced significantly when the Royal Society decided to equip his private observatory at Tulse Hill with first-class instruments for spectroscopic research. These were an 18-in. reflector and a 15-in. refractor, with suitable spectroscopic attachments, constructed by the firm of **Howard Grubb** of Dublin and set up in 1871 in a new dome in his garden.

At the age of 51 and still a bachelor, in 1875 Huggins married Margaret Lindsay Murray of Dublin, a young woman almost 25 years his junior with an enthusiasm for astronomy. They had no children, but theirs was an unusually happy and scientifically productive union.

The couple soon embarked on a substantial program of photographic stellar spectroscopy with the 18-in. reflector. They were the first to make serious use of dry plate photography, then a recent innovation. They concentrated on high dispersion spectra, carried out in spite of the increasingly unfavorable sky of London. Their beautiful and useful *Atlas of Representative Stellar Spectra*, the assembled fruit of these labors, was published in 1899. One of their most studied objects was the Orion Nebula, its chief interest being the identification of the green emission line, then attributed to a mystery element, *nebulium*. This work brought Huggins into conflict with his rival spectroscopist **Joseph Lockyer**, whose meteoritic hypothesis attributed the unknown line to magnesium. In this debate Huggins was to prove correct, though the identity of *nebulium* (ionized oxygen and nitrogen) was not resolved until the 1920s by **Ira Bowen**.

Chiefly remembered as a spectroscopist, Huggins was in fact what a recent historian has called an eclectic researcher with involvement in several projects. He put a great deal of effort into finding a way of observing the solar corona without a total eclipse, but without success. Toward the end of his career, challenged by the superior climatic conditions at modern observatories such as the Lick Observatory in California, the Huggins gradually retired from observational astronomy and turned to laboratory spectroscopy, notably the spectra of radioactive substances. Huggins's observational career came formally to an end in 1908 when the Royal Society telescopes were transferred from Tulse Hill to the Solar Physics Observatory in Cambridge. His devoted wife collected and published his scientific papers and his important public addresses.

William Huggins was awarded the Gold Medal of the Royal Astronomical Society for a second time in 1885, and the Rumford Medal (1880) and Copley Medal (1898) of the Royal Society. He was knighted in 1897 on the occasion of the diamond jubilee of Queen Victoria, and was among the initial 12 recipients of the Order of Merit when it was instituted in 1902. Huggins served as president of both the Royal Astronomical Society and of the Royal Society.

Huggins died at the age of 86, a revered scientific elder statesman. He was cremated, and his ashes laid in Golders Green cemetery in London.

Mary T. Brück

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Hulburt, Edward Olson

Born **Vermillion, South Dakota, USA, 12 October 1890**
Died **Easton, Maryland, USA, possibly 1966**

American optical physicist Edward Hulburt received his AB from Johns Hopkins University in 1911 and his Ph.D. in physics there in 1915, with a thesis on the reflecting properties of metals in the ultraviolet. After holding teaching positions at Hopkins and Western Reserve universities, he was appointed the superintendent of the physical optics division of the Naval Research Laboratory in Washington, in 1924. He spent the rest of his career there, becoming director of research in 1949 and retiring in 1956. During World War I, Hulburt served in the Signal Corps, rising to the rank of captain, and during World War II he was part of the army/navy vision committee.

Hulburt worked on a wide variety of problems in the propagation and measurement of both light and radio waves, investigating electron tubes as radio detectors as early as 1920. He developed a theory of aurorae and magnetic storms, in which ultraviolet [UV] radiation from the Sun was the primary energy source, in 1929. The UV radiation was directly measured in 1947 from a captured V2 rocket, though it turns out that X-rays and particle radiation from the Sun are also important for these phenomena. Hulburt observed the Sun and Moon from Antarctica starting in 1931, participated in a number of solar eclipse expeditions, and was part of the observing team for the Bikini bomb tests in 1946. He also made contributions to the understanding of the structure of the Earth's upper atmosphere and ionosphere and to propagation of radio waves in it. His work was of direct relevance both to the interests of the navy and to astronomy.

Hulburt was associate editor of the *Journal of Optics* (1938–1947), a fellow of the American Physical Society and of the American Association for the Advancement of Science, and part of the United States National Committee for the International Geophysical Year (1957–1958). He received medals from the Optical Society of America and the American Geophysical Union. His 1920 marriage produced two children.

Virginia Trimble

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Humason, Milton Lassell

Born **Dodge Center, Minnesota, USA, 19 August 1891**
Died **Mendocino, California, USA, 18 June 1972**

American observational astronomer Milton Humason is eponymized in the Humason–Zwicky stars, but his most important contribution was undoubtedly the exposure of spectrograms of large numbers of faint galaxies on the Mount Wilson Observatory 100-in. and Palomar Mountain Observatory 200-in. telescopes, which were used to estimate values of the Hubble constant from 1929 to 1956, including values reported by **Edwin Hubble** himself. Humason had roughly an eighth-grade education, plus an honorary D.Sc. (1950) from Lund Observatory. He married Helen Dowd in 1910 or 1911, and they had one son.

The involvement of Milton Humason with Mount Wilson Observatory began during the construction of the 100-in telescope (which saw first light in 1917). Humason was a mule packer and driver hauling equipment and supplies up the 10-grade dirt road. When the telescope was completed, he was hired as a janitor, and, 2 years later, director **George Hale** appointed him to the scientific staff as a member of the research division. Hubble early on claimed Humason in the role of his night assistant, and that role grew larger and more exacting, until Humason was himself obtaining large numbers of images and spectra, used for finding Cepheid variables in external galaxies and measuring the redshifts of those galaxies. He remained a member of the research division until his retirement in 1957, with less formal titles of assistant astronomer, observatory secretary (1948–1957, with major responsibilities for responding to requests from the public), and astronomer (1954–1957). Unlike Hubble, Humason lived to use the 200-in. telescope (commissioned in 1948) extensively, pushing the search for Cepheid variables to galaxies outside the local group and the quest for larger redshifts up to about 60,000 km/s.

Humason's great skill was in getting the always temperamental large telescopes to produce the best images and spectra of which they were capable, over exposure times that often stretched to an entire night, and sometimes several nights. His targets besides distant galaxies included supernovae, novae long past peak light, and very faint stars, including white dwarfs. Some of these were collaborations with **Fritz Zwicky**, in particular the faint, blue, high-latitude Humason–Zwicky stars, which turned out to include a number of white dwarfs and related stars, some post-asymptotic giant branch stars and subdwarfs, old novae, and even a few quasi-stellar objects.

While Humason spent nights at the telescopes, Hubble was measuring Cepheid light curves, shapes, sizes, and brightnesses of whole galaxies, and their redshifts. Some papers were published under one name, some under the other (including the 1929 pair that is cited as the discovery of the expansion of the Universe), and some under both, but Hubble took the lead role in both formulating the problems and writing up the results. The program continued after Hubble's death. An important 1956 paper was published by Humason, **Nicholas Mayall**, and Allan R. Sandage, reporting colors, sizes, and apparent brightnesses of 625 galaxies, obtained from photographic plates, and presenting a recalibration of the Hubble constant (expansion rate of the Universe). The three astronomers lowered the numerical value from the 250 km/s/Mpc of **Walter Baade** to about 180 km/s/Mpc, and so increased the best-guess age of the Universe from about 4 billion years to about 5 (very close to the age of the Solar System). Still later work has lowered H_0 to about 70 km/s/Mpc and increased the most likely age to about 14 billion years. The final word is surely not in on these numbers.

Humason handed on his knowledge of observing procedures to Sandage, Mayall, and a few others, but reportedly, his skills in fishing with the night assistants, playing poker with all comers who were rained out at the observatory, hiding empty whiskey bottles – Mount Wilson and Palomar were both nominally dry – and somehow interacting productively with all manners, classes, and sorts of people have not been duplicated since. Professional recognition came relatively late, with Humason's 1950 honorary D.Sc. (promoted by **Knut Lundmark**, 1950) and election as a foreign associate of the Royal Astronomical Society at the time of his retirement in 1957. His death, by heart attack, was sudden and unexpected.

Eugene F. Milone and *Virginia Trimble*

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Humboldt, Alexander Friedrich Heinrich von

Born **Berlin, (Germany), 14 September 1769**
Died **Berlin, (Germany), 6 May 1859**

While Alexander Humboldt certainly contributed greatly to the astronomical sciences, his main achievement is to have laid the scientific foundations of physical geography. From his extended travels, he collected a considerable amount of material about the astronomical determination of positions on the Earth, following the techniques of **János von Zach**. Especially noteworthy are his South American observations of the zodiacal light and the meteor shower of 12 November 1799, as well as his later efforts (with **Carl Gauss**) to set up geomagnetic observation stations, his leading role in the establishment of a new observatory in Berlin, and his encouragements to young astronomers and mathematicians.

Humboldt studied at the universities of Frankfurt an der Oder and Göttingen, as well as at the Mining School of Freiberg, Saxony, and was for a short time *Oberbergmeister* (general mining inspector)

in Franconia. During a journey to Paris, he met and befriended important scientists (such as the botanist Aimé Bonpland and the astronomer and physicist **François Arago**). From there, he set off on great scientific expeditions to South and Central America (Venezuela, Colombia, Ecuador, Mexico, and Cuba), and later to Central Asia (Russia, the Ural, Altai, and the Caspian Sea).

Humboldt's masterwork *Kosmos* portrays the natural sciences of his time on the basis of his deep understanding of the various problems arising from a manifold of scientific disciplines. With this, he qualifies as one of the greatest universal thinkers of all times. During the many studious years Humboldt devoted to this work, he sought the assistance of many specialists so as to be able to paint a detailed portrait of science in its latest state. He had an extensive correspondence with the most significant astronomers of his days, such as **Frederich Bessel**, **Heinrich Schumacher**, **Johann Encke**, **Johann Galle**, *etc.*, who provided him with new data, assessed new scientific productions, advised him about precise conceptual formulations, and went over parts of the book.

Far from being a work of popularization of the natural sciences, *Kosmos* is a demanding depiction of the Earth and the heavens. Volumes I and III are especially devoted to the "cosmic part." The astronomical exposé starts with the description of the starry sky, moving from planets and their satellites, comets (their physical nature and trajectories), and asteroids to single stars (their color, distance from the Earth, *etc.*) and their systems (double and multiple stars and star clusters), to the Milky Way and the nebulae. Humboldt constantly endeavored to take the latest results into account, like the measurement of parallax by Bessel, **Friedrich Struve**, and **Thomas Henderson**; the motion of the constituents in double-star systems after Bessel; and the discovery of new asteroids.

Humboldt paid great attention to the origin of cosmic bodies and of their systems. His detailed presentation of **William Herschel**'s work in this domain attests to his deep awareness of its far-reaching consequences. Nor did Humboldt omit to mention objections against the existence of unorganized diffused matter in the Universe (gas and dust) that stemmed from the fact that the great reflector of **William Parsons** had successfully resolved distant nebula into stars. Throughout, he engagingly integrated considerable historical materials from the times of Greek philosophers, the classic period of Antiquity, the Islamic world, the Middle Ages, and modern natural philosophy up to his time.

Occurring after Humboldt's series of public lectures in Berlin, a great social event in the Prussian capital, the publication of *Kosmos* caused a sensation. This success also derived from Humboldt's brilliant combination, rarely seen before or after him, of scientific accuracy (even while treating topics in detail) and a vivid and poetic use of language. The book was enthusiastically bought and read, was quickly translated into several languages, and played an eminent role in the cultural history of the 19th century. With it, Humboldt secured for himself a highly esteemed position in the history of astronomy, too.

Jürgen Hamel
Translated by: *David Aubin*

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Humphreys, William Jackson

Born **Gap Mills, Virginia, USA, 3 February 1862**
Died **Washington, District of Columbia USA, 10 November 1949**

American physicist and meteorologist William Humphreys made laboratory measurements of the effects of gas pressure on the wavelengths and widths of absorption lines produced by common elements, which permitted estimates of the pressure, and therefore the location of the layer of the Sun's atmosphere responsible for its absorption lines. The son of Andrew Jackson Humphreys and Eliza Ann (*née* Eads) Humphreys was born and raised in a rural setting. He attended the local public school and a high school in Pomeroy, Ohio. After studying at Washington University and Lee University in Lexington, Virginia, Humphreys earned his BA in 1886 and a degree in mechanical engineering 2 years later. For the next 5 years, 1889–1894, he taught physics at Miller school near Crozet, Virginia, and at Washington College, Chestertown, Maryland, later pursuing advanced study in physics and chemistry at the University of Virginia and at Johns Hopkins University, Baltimore (under **Henry Rowland**'s supervision), where he defended his Ph.D. thesis in 1897. Thereupon, until 1905, Humphreys was instructor of physics at the University of Virginia, teaching physics and taking part in two eclipse expeditions with the United States Naval Observatory, one to Georgia in 1900, the other to Sumatra in 1901. From 1905 until his retirement in 1935, Humphreys worked for the United States Weather Bureau, the first 4 years as supervising director at the newly founded observatory on Mount Weather, from 1911 to 1934 also serving as part-time professor of meteorological physics at the George Washington University. On 11 January 1908, he married Margaret Gertrude Antrim, who survived him; they had no children.

While in Baltimore, Humphreys worked on problems of astrophysics, mostly on what is called the pressure shift of spectral lines emitted by gases under pressures higher than 1 atm. Together with Rowland's other Ph.D. student at the time, Fred Mohler, and Rowland's personal assistant, Lewis E. Jewell, he published various papers in the *Astrophysical Journal*, summarizing his work for the Ph.D. Before turning to meteorology as his main occupation, specializing in the isothermal layers of the stratosphere, peculiar optical phenomena such as halos, rainbows and flashes, and weather forecasting, Humphreys also worked on other effects of precision spectroscopy, such as the magnetic splitting of spectrum lines, known as the Zeeman effect, and on related atomic models such as H. Nagaoka's.

Aside from several dozen articles for the *Astrophysical Journal, Physical Review, Science, etc.* (many of his articles were collected in his *Weather Rambles* [1937]) Humphreys also published several books on meteorology: *Physics of the Air* underwent three editions (1920, 1928, and 1940). A highly entertaining autobiography, *Of Me* (Washington, 1947), includes a full bibliography of his writings. But most famous is *Snow Crystals*, coauthored with Wilson A. Bentley in 1931 – Humphreys prepared Bentley's exquisite microphotographs for publication and wrote the text.

In 1904, Humphreys served as secretary of the section on the physics of the electron at the *International Congress of Arts and Sciences* in Saint Louis, Missouri. He was president of the American Meteorological Society (1928/1929), the *Washington Academy of Sciences* (1922), the *Philosophical Society of Washington* (1919), and the *Cosmos Club*. The American Geophysical Union appointed him national chairman (1932–1935), and Humphreys served as general secretary of the American Association for the Advancement of Science (1924–1928), and as chairman of its Section B (Physics) in 1917. His popular treatise *Ways of the Weather* was recommended by the Book-of-the-Month Club, and physics literary excellence earned him honorary membership in the Eugene Field Society.

Klaus Hentschel

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Ḥusayn, Hasan and Muḥammad

Ḥasan Ḥusayn

Flourished **Isfahan, (Iran), second half of the 17th century**

Muḥammad Ḥusayn

Flourished **Isfahan, (Iran), second half of the 17th century**

Ḥasan Ḥusayn and Muḥammad Ḥusayn were two instrument makers in Isfahan, Iran, and were somehow associated with the various better-known makers of fine astrolabes and other instruments that grace many a museum the world over. Their two names, however, are new to the literature. They made European-style inclined sundials fitted with compass dials; two instruments made by each one of them are of particular historical interest because the horizontal bases for the sundials are engraved with world maps. These are fitted with complex mathematical grids that preserve direction and distance to Mecca at the center. The former (discovered in 2001) is more carefully engraved than the latter (discovered in 1995), and a third example, unsigned and now missing sundial and compass (known since 1989), may also be by Ḥasan Ḥusayn. The underlying mathematics and the geographical data used for some 150 localities on each map are entirely within the Islamic tradition; the former is attested in Arabic treatises from 10th and 11th centuries, and the latter is taken from a 15th-century source. Indeed, Muslim interest in projections preserving direction and distance to the center goes back to **Ḥabash al-Ḥāsib** and **Bīrūnī**, each of whom wrote on the astrolabe with a melon-shaped ecliptic on the rete. However, we are still looking for a 17th-century or earlier Arabic or Persian treatise on the construction of the map-grids, or indeed for any new information on the school of instrument makers from which these remarkable objects stem.

David A. King

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Hussey, William Joseph

Born **near Mendon, Ohio, USA, 10 August 1862**
Died **London, England, 28 October 1926**

Binary star astronomer William Hussey published numerous research articles and reports, but his real strength was in academic and scientific management.

Hussey was the son of John Milton and Mary Catherine (*née* Severns) Hussey. He enrolled at the University of Michigan in 1882, but did not have sufficient funds to continue after his sophomore year. Hussey took a job as a railway surveyor until he could save enough money to return to the university. He finally graduated in 1889 with a degree in civil engineering.

After working for the United States Nautical Almanac Office for a short time, Hussey returned to the University of Michigan as an instructor. He was acting director of the Detroit Observatory in 1891/1892.

Hussey then took up a professorship at Stanford University and served as a volunteer assistant at the Lick Observatory. From 1896 to 1905 he was a staff astronomer at the Lick Observatory. During this period Hussey worked on the astrometry of comets, planetary satellites, and double stars. He developed a mastery of the techniques of micrometrical observation. In 1899 Hussey and **Robert Aitken** commenced a survey of all double stars brighter than ninth magnitude between the North Celestial Pole and −22°. He discovered 1,327 double stars in the process, and received the Lalande Medal of the French Academy of Sciences for his double star work. Hussey also conducted a survey of possible future observatory sites in California, Arizona, and Australia for the Carnegie Institution. His 1903 report concluded that both Mount Wilson and Palomar Mountain were excellent locations.

In 1905, Hussey led a Lick Observatory expedition to observe a solar eclipse in Egypt. Shortly thereafter he accepted the position of director of the Detroit Observatory and professor of astronomy at the University of Michigan. The astronomy program at Ann Arbor had been stagnant for some years. The Detroit Observatory itself was an antiquated facility with no equipment for astrophysical research. Hussey set out to bring the program up to date and proved equal to the challenge. He arranged for the observatory to be enlarged, and an instrument shop to be established. A 37½-in. reflecting telescope equipped with a spectrograph was installed in 1911. Hussey instituted the *Publications of the Observatory of the University of Michigan* to record and distribute the observatory's research. He was successful in adding new positions to the department, hiring **Ralph Curtiss**, Will Carl Rufus, and **Richard Rossiter**. The number of astronomy students greatly increased as well.

In 1911, Hussey was offered the directorship of the La Plata Observatory in Argentina. He arranged to divide his time between La Plata and Ann Arbor, an arrangement that lasted until 1917. He hoped to extend his double star survey to the South Celestial Pole, but difficulties at La Plata frustrated his plans.

Hussey had a long-standing interest in Southern Hemisphere astronomy. He had been planning a southern observatory for the University of Michigan as early as 1910. With the financial support of R. P. Lamont, a former classmate, Hussey placed an order for a 27-in. refractor. In 1923/1924 he traveled to South Africa to select a site. When the telescope was ready for shipment Hussey set out for Africa to supervise its installation. He stopped in England on the way, and gave an address to the Astronomical Club in London after that meeting. He died suddenly later that night.

Hussey was a member of what would become the American Astronomical Society [AAS] (secretary 1906–1912, councilor 1919–1921 and 1924–1926), member of the Astronomical Society of the Pacific, member of the American Mathematical Society, an honorary member of the Astronomical Society of Mexico, and a foreign associate of the Royal Astronomical Society. As AAS secretary, he was responsible for the printing (at Ann Arbor) of the first two volumes of the *Publications of the Astronomical and Astrophysical Society of America* (1910, 1915).

Rudi Paul Lindner

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Huth, Johann Sigismund Gottfried

Born **Roslau, (Sachsen-Anhalt, Germany), 2 May 1763**
Died **Dorpat, (Tartu, Estonia), 28 February 1818**

Johann Huth was an asteroid and comet observer who first organized astronomy at Kharkov University. Until 1801 he engaged himself mostly in studying applied mathematics, architecture, applied mechanics, and physics, but appears to have dedicated most of his spare time to astronomy from about this year. Huth was a professor of mathematics and physics in Frankfurt an der Oder.

Huth was one of the astronomers who searched for Ceres in December 1801. He thought he had found it, but whatever object he observed, it was not Ceres. In the following year, Huth visited England to familiarize himself with the main observatories, as well as with opticians and astronomical instrument makers. He made professional contacts with various astronomers, including **William Herschel**. He obtained from Herschel the English astronomer's detailed study of (1) Ceres and (2) Pallas, which he then communicated to **Johann Schröter** in Lilienthal. By the time Schröter wrote about this in his 1805 asteroid book, we find Huth referred to as *Hofrath* (a Prussian privy councilor).

In a letter to Herschel, Huth set forth his noteworthy considerations about the origin of minor planets and proposed an assumption, which was confirmed later, that there will be discovered at least 10 such bodies, together with Ceres and Pallas. "But," adds Huth, "because of their [minor planets'] smallness it will always be difficult to discover them and find them again until we have special, very detailed, charts at least of the zodiac."

In the same letter Huth dismissed Herschel's opinion that Ceres and Pallas are not real planets. The dismissal was probably the reason why Herschel left unanswered Huth's interesting and provoking letter.

Upon his return from England, Huth started an observatory, equipped with quality instruments made in London, at his own expense and in his own house. He allowed students and amateurs to use it and offered them his teaching on how to carry out astronomical observations. Huth was particularly interested in the physical structure of celestial bodies, double stars, nebulae, the zodiacal light, *etc*. He was also one of the first to suggest the existence of snow on Mars. The results of his observations were published in 1803–1810 in the *Berlin Astronomical Yearbook*. Apart from his observations, Huth also surveyed the sky, and discovered three comets during a comparatively short time.

Observing from Frankfurt an der Oder, Huth independently discovered 2P/Encke on 21 October 1805. One month later, he also found what was to become known as comet 3D/Biela. On 29 September 1807 he independently discovered the great comet C/1807 R1. For his discoveries Huth was awarded a money prize, which he shared with **Friedrich Bessel**.

In 1807 Huth accepted an invitation to join Kharkov Imperial University in the capacity of a professor of applied mathematics. The university offered to buy abroad at its expense all the necessary physical and astronomical instruments. On 27 August 1808, Huth's name was added to the staff, and his luggage arrived in Kharkov on 10 November 1808. (It consisted of 31 boxes, weighed 427 poods [1 pood = 16.38 kg], and was worth 35,288 rubles; together with physical and astronomical equipment it consisted of books, a collection of minerals and shells, animal bones and stuffed animals, and some ancient artifacts.)

Having in his possession an 8-in. reflecting telescope, a Dollond 2-in. refractor, a vertical quadrant, a sundial, and a number of other astronomical devices, Huth decided to organize an astronomical study room at the university, which he accomplished in 1808.

In July 1808, he addressed his project to the board of trustees of the university, in which he proposed (1) to organize a small observatory for astronomical observations, (2) to measure a degree of arc of the geographic meridian and parallel, and (3) to carry out daily meteorological observations both in Kharkov and in the gymnasiums of the Kharkov region.

(Thus the idea about the establishment of the Russian degree measurement was first proposed in Kharkov University. Later it was developed by **Friedrich Struve**, who put it into practice at Pulkovo Observatory.)

The board was interested in the observatory project, so Huth proposed for it a two-room "rotunda" where astronomical instruments could be stored and the observers could stay during the winter months. The money was found and construction begun, but progress was slow and only by the 1810/1811 academic year was it finished. Observations were not carried out (or were of brief duration), for Huth left Kharkov in 1811. The university remained for quite some time without an astronomer, and the "rotunda" was used as a storage space.

Ernst Knorre, professor of mathematics and director of the observatory in Dorpat died on 1 December 1810. His astronomical observations were limited since the observatory was not completed when he died. The vacant posts were offered to Huth. In May 1811 Huth traveled to Dorpat. Like Kharkov, Dorpat University was of recent date: Even though it had been founded in 1632, it was suppressed in 1656 and did not reopen until 1802.

At Dorpat University Huth was in charge of mathematics and, formally, of the observatory, where he helped **Wilhelm Struve** master the equipment. Struve had been in Dorpat since 1808; he graduated from the university in 1810 and was appointed observer to assist Huth in 1813.

Huth was chronically sick. Although a capable scholar, his debilitated state left him barely able to manage his teaching responsibilities. He rarely visited the observatory. Its major instrument, a transit telescope by Dollond, was not used until Struve took over in 1813.

Clifford J. Cunningham

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Huygens, Christiaan

Born **The Hague, the Netherlands, 14 April 1629**
Died **The Hague, the Netherlands, 8 July 1695**

Christiaan Huygens correctly interpreted the nature of Saturn's rings and made significant contributions to mathematics and to telescope and clock design. Huygens was the second son of Constantijn Huygens and Suzanne van Baerle. His father was the highest-ranking Dutch civil servant, secretary of state to several *stadholders*. Interested in arts and sciences, he was a patron to **René Descartes**. Christiaan, educated by private governors and tutors, enrolled in law and mathematics at Leiden University in 1646. He became an enthusiastic student of Frans van Schooten, Jr., who had just published the works of **François Viète** and was then editing an

annotated Latin translation of Descartes's *La Géométrie* for publication. Both works were crucial for the new analytical geometry. Van Schooten and Huygens became friends; later Huygens contributed a paper on probability theory to Van Schooten's *Exercitationes mathematicae* (1657). In 1649, Huygens returned home and after briefly considering a diplomatic career, he chose science and mathematics. In the 1650s his skills in both grew steadily and were noticed by the international community, particularly in Paris. Having met Robert Boyle and the Gresham College circle in London, Huygens was nominated, in the autumn of 1663, as a fellow of the Royal Society.

Huygens made several trips to Paris, and the news that Jean-Baptiste Colbert was organizing an academy of science, financially supported by Louis XIV, brought hope for a paid scientific career. Constantijn promoted Christiaan's career in France. Christiaan was invited to compose the draft of a foundational text that could define goals and rules of the new institution. In 1666 Christiaan was among the first nominated members of the Académie royale des sciences and moved to Paris. There, in 1676, he met **Gottfried Leibniz**, who asked his advice on mathematics; within a decade, Leibniz would become a leading mathematician.

Huygens remained in Paris until 1681, when he retired to the Hague for reasons of health. (On the death of Colbert, in September 1683, Huygens's presence in Paris would no longer have been appreciated: The revocation of the Edict of Nantes in 1685 by Louis XIV, made it impossible for Protestants to be nominated for important posts.) Until his death, Huygens lived and worked either in the Hague or at the family's country estate at Voorburg, interspersed with trips abroad such as one to London in 1689 to meet with **Isaac Newton**, Fatio de Duillier, **Edmond Halley**, and Boyle.

In the early 1650s, Huygens and his brother Constantijn started grinding lenses to construct Keplerian telescopes. Christiaan was well aware of the ratio of focal distances as the magnification factor and tried to grind ever-greater objectives. In March 1655, in trying out one of his first telescopes, he began to observe Saturn, the most intriguing of all planets since **Galileo Galilei**'s noticing its "ears" (*ansae*). His small tract *De Saturni luna observatio nova* (1656) summarized his first discovery, the new satellite, and announced the solution of the riddle of Saturn's appearances.

(In using the same eyepiece, he had made two objectives such that the length of his tubes became either 377 cm or 722 cm. The magnification of the first was about 50 times, that of the second twice as much. It has been deduced that the eyepiece was adjustable in the tube. Huygens used a diaphragm just behind the objective in order to reduce aperture and chromatic abberation.)

On 25 March, Huygens started his observations of Saturn, which was retrograding in Pisces at the time; its form appeared to be almost spherical, the *ansae* being rather narrow. Huygens noticed two stars in its neighborhood. Within a few days, he concluded that one of these followed the planet. This was the first satellite discovered since Galilei. Three years of observations from March 1655 yielded the sidereal and synodic periods. From the end of November 1655, the *ansae* became invisible, and the round phase remained, together with the dark equatorial band. The *ansae* reappeared in June 1656; in October the whole of Saturn had recovered almost the same form as before in November 1655. From 19 February 1656 onward Huygens used the long telescope and now definitely noticed the elliptical form of the *ansae* and the dark band that joined both. On 5 March 1656, he was sure enough to summarize his conclusion.

In his view, the ring would be a stable entity because of its symmetrical form and its position in Saturn's vortex. The ring was inclined to the ecliptic by about the same angle as our Equator, so Saturn should manifest equinoxes, just like the Earth. He realized that the "ringless" appearance showed up when the Earth passed through the ring plane.

At this time Huygens studied the problem of accurate time measurement. Aware from Galilei of the isochronous nature of pendula, Huygens was the first, in 1657, to maintain the swing and transmit the sequence to the indicator plate of clockwork. He developed the mathematics and the mechanical way for attaining perfection in isochronicity. To correct for the day's inequality, he developed equation-of-time tables (1662). In 1673, Huygens summarized his research in *Horologium oscillatorium*. He later became aware of the spring balance (1675); in nautical practice, the rapid corrosion of the spring metal and its temperature dependence turned out to be insurmountable obstacles.

He invented the Huygens eyepiece named for him in 1662, a compound lens consisting of two parallel plano-convex lenses, with focal distances in the ratio of about 1:4. When mounted such that the focal point of the objective is within the focal reach of the outer ocular lens, sharp, hardly deformed images in an enlarged field result. In grinding ever-greater objectives up to one with a focal length of about 60 m, Huygens was halted by dimensions of the tube. In the 1680s he tried a huge tubeless construction (an aerial telescope). Being too sensitive to wind, it was unsuccessful.

In 1676 **Ole Römer** worked out his proof for the finite velocity of light and the technique for measuring it by comparing the time intervals for eclipses of Io near Jupiter's opposition and conjunction. Jupiter's satellites had been studied in hopes that they might provide a measurement for longitude at sea. Huygens's pendulum clocks, with their increasing accuracy over long periods, had come in due time. The difference Römer measured of 22 min over half a terrestrial year constituted the time for light to travel over the diameter of the Earth's orbit. Given the astronomical unit [AU] in terms of **Willibrord Snel** and Huygens's data of 1.54×10^8 km, Römer calculated a value of 1.17×10^5 km/s for the velocity of light. This was the missing link in Huygens's theoretical considerations of light from 1665 onward; his mature thoughts appeared in his 1690 *Traité de la lumière*.

In 1687 Newton sent Huygens a copy of his *Principia*. Huygens was not convinced by Newton's plea for gravitation as an action at a distance that followed an inverse square law, but was impressed.

Huygens's last contribution concerned the relative distances of the fixed stars, all considered as suns of the same brightness as ours and having planets. This appeared posthumously in his *Kosmotheoros* (1698). The first book opens with a discussion of the plurality of worlds, an issue of interest thanks to **Bernard de Fontenelle**. Huygens's system is Copernican with Keplerian ellipses, which he defends on various grounds. Huygens then discusses the relative dimensions of the planets and the Sun. For Mercury, he used **Johannes Hevel**'s value of 1/290th of the Sun's diameter. Huygens argues that all planets are similar, and what holds for the Earth must of necessity hold for all: solid massy objects, with flora and fauna and also human-like inhabitants. Kepler's laws are verified for the satellites of Jupiter and Saturn. The thickness of Saturn's ring is estimated at 600 German miles (about 4,519 km). The inhabitants of the other planets will of course have the same view of the fixed stars. What may be said of our Moon holds equally for those of Jupiter and Saturn. If it is evident that there are mountains and valleys on our Moon, so there are on the others. However, there is in all probability neither water nor air on both our Moon and those of the outer planets. Indeed, the observed disk of the Moon, with its sharp boundary, does not allow for an atmosphere, so life is unlikely.

Recent determinations of the AU by **Giovanni Cassini** and **John Flamsteed**, employing parallax measurements, are mentioned (10,000–11,000 Earth diameters), but Huygens's value was 12,000 given the uncertainty of parallax measurements. For the Earth's diameter, he adopted **Jean Picard**'s 1671 value (1.27×10^4 km). Huygens then proposes a way to determine the distances between our Sun and the stars: Reduce the Sun's appearance until it is like that of Sirius. This may be realized by reducing the aperture of the 12-ft. telescope with a very small pinhole of 0.19 mm, which works in the proportion of 1:182. A second reduction, 1:152, is brought about by putting a microscope's spherical lens in the pinhole. Thus when the Sun has about the same brightness as Sirius, so that Sirius is 182×152 times smaller than the Sun, its distance will be about $182 \times 152 = 27{,}664$ AU. The Universe is otherwise of undetermined dimensions, since the stellar magnitudes suggest ever-growing distances.

Huygens designed the first Copernican orrery – using the method of continued fractions – that was executed by Johannes van Ceulen in 1682.

Henk Kubbinga

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Hypatia

Born **Alexandria, (Egypt),** ***circa*** **370**
Died **Alexandria, (Egypt), March 415**

Hypatia, famed for her beauty, intelligence, and virtue, was not only the head of the Alexandrian Neoplatonic school of philosophy but also the first significant female mathematician and astronomer.

Hypatia's first teacher was her mathematician–astronomer father, **Theon of Alexandria**, who may have been director of the Alexandrine Library, and with whom she may have coauthored a commentary on **Ptolemy**'s *Almagest*. She traveled to Athens to study under Plutarch and his daughter Asclepegeneia. Upon her return to Alexandria, she became a popular teacher of geometry, algebra, and astronomy at the university, where her students included both Christians and pagans. Not only her scientifically rational thought but also her friendship with Orestes, Alexandria's Roman Prefect, aroused the enmity of Cyril, Bishop of Alexandria, Orestes's political enemy.

Much of what we know about Hypatia comes from her wide correspondence and from the Suda lexicon, the massive 10th-century Byzantine–Greek encyclopedia covering ancient literature, history, and biography. Among her correspondents was **Synesius**, Bishop of Ptolomais, who remained Hypatia's devoted disciple after studying under her, and who queried her about designs for a planisphere, an astrolabe, a hydrometer for measuring specific gravity, and a device for distilling water.

According to the Suda lexicon, in around 400, at the age of 31, Hypatia became head of the Alexandrine Neoplatonic school. The Suda also identifies Hypatia as the author of commentaries on the *Arithmetica* of Diophantus of Alexandria, the *Conics* of **Apollonius**, and the astronomical canon of Ptolemy, none of which is extant. Other sources about Hypatia include Socrates Scholasticus's 5th-century *Ecclesiastical History* and the theologian Photius's 9th-century *Bibliotecha*.

All sources about Hypatia agree on the horrific circumstances of her death. In March 415, a mob forcibly removed her from her chariot, stripped her, and used oyster shells to slash and pelt her to death. The parts of her dismembered body were then scattered throughout Alexandria.

Naomi Pasachoff and *Jay M. Pasachoff*

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Hypsicles of Alexandria

Flourished **Alexandria, (Egypt), 150 BCE**

Hypsicles was a mathematician and astronomer, active in Alexandria in the first part of the second century BCE. His book *On Rising Times* used a Babylonian arithmetical scheme to calculate the rising times for zodiac signs, adapted to the latitude of Alexandria. This work was the first in Greek to use sexagesimal arithmetic and to divide the ecliptic into 360° of arc. Hypsicles also wrote the so-called *Fourteenth Book of Euclid's Elements*, which dealt with the icosahedron and the dodecahedron.

Katherine Bracher

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I

Ibn Abī al-Fatḥ al-Ṣūfī: Shams al-Dīn Abū ˁAbd Allāh Muḥammad ibn Abī al-Fatḥ al-Ṣūfī

Flourished **Cairo, (Egypt), late 15th century/early 16th century**

Ibn Abī al-Fatḥ al-Ṣūfī was an important Egyptian astronomer who wrote some 26 works on astronomy. These works include astronomical instruments, tables for timekeeping and other purposes, and important studies on **Ulugh Beg**'s *Zīj*. His name and death date have been variously reported by both historical and modern sources. He has sometimes been confused with his father who pursued similar studies and had a similar name.

Although little is known about his life, we can surmise that Ibn Abī al-Fatḥ al-Ṣūfī was probably first educated by his father. He informs us in his *Nihāyat al-rutba fī al-ˁamal bi-jadwal al-nisba* that his education was guided by the famous Egyptian astronomer **Sibṭ al-Māridīnī**. Indeed, his approach to astronomy, relying on mathematics and arithmetic and avoiding philosophical content, does place him within the tradition of the "Egyptian school" that began with **Ibn al-Hā'im** in 13th-century Egypt, was further developed in the 14th-century Maghrib with **Ibn al-Bannā'**, continued with **Ibn al-Majdī**, and matured with Sibṭ al-Māridīnī.

There are 26 works attributed to **Ibn Abī al-Fatḥ al-Ṣūfī** that are currently extant; some of these may, though, be actually by his father. These works include astronomical and timekeeping tables, treatises dealing with astronomical instruments, and reworkings of **Ulugh Beg**'s *Zīj*. In his *Tashīl zīj Ulugh Beg* (or *Mukhtaṣar zīj Ulugh Beg*), Ibn Abī al-Fatḥ al-Ṣūfī recalculated Ulugh Beg's tables, originally prepared for Samarqand, for Egypt. Similarly, Abū al-Fatḥ al-Ṣūfī wrote another work consisting only of tables called *Bahjat al-fikr fī ḥall al-shams wa-'l-qamar*. Undoubtedly, his most important astronomical study is *Zīj Muḥammad ibn Abī al-Fatḥ al-Ṣūfī*, which purports to be an emendation of *Zīj-i Ulugh Beg*. His student, **Taqī al-Dīn**, mentions in his *Sidrat muntahā al-afkār* that Abū al-Fatḥ al-Ṣūfī improved the arithmetic of the *zīj*, as well as made new observations (although he provides little detailed information about their details).

Ibn Abī al-Fatḥ al-Ṣūfī wrote several books on astronomical instruments based on the work of **Ibn al-Shāṭir** and Ibn al-Sarrāj. He wrote on a quadrant called *al-rubˁ al-mujannaḥ* and on a timekeeping device called *ṣandūq al-yawāqīt* that was invented by Ibn al-Shāṭir. In other works he describes two little-known instruments called the "Goose Chest" and the "Crow Wing" and how to use sand clocks.

Ibn Abī al-Fatḥ al-Ṣūfī's influence was widespread and enduring as indicated by a commentary on his *Nubdhat al-isˁāf fī maˁrifat qaws al-khilāf* by the Egyptian astronomer Ramaḍān ibn Ṣāliḥ al-Khwānakī (died: 1745). He also trained a number of students. He encouraged his student Yaḥyā ibn ˁAlī al-Rifāˁī to translate Ulugh Beg's *Zīj* from Persian into Arabic. This translation made this *Zīj* more widely accessible in Ottoman lands; there are currently more than 20 extant copies. Ibn Abī al-Fatḥ al-Ṣūfī's most important student, though, was the great astronomer Taqī al-Dīn, who corrected and completed Ulugh Beg's *Zij* and would become the founder of the Istanbul Observatory.

İhsan Fazlıoğlu

Alternate name

Abī al-Fatḥ al-Ṣufi

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Ibn Abī al-Shukr: Muḥyī al-Milla wa-’l-Dīn Yaḥyā Abū ˁAbdallāh ibn Muḥammad ibn Abī al-Shukr al-Maghribī al-Andalusī [al-Qurṭubī]

Died **Marāgha, (Iran), June 1283**

Ibn Abī al-Shukr carried out a large-scale project of systematic planetary observations, which led to the determination of a number of new astronomical parameters. He belonged to the group associated with the Marāgha Observatory, several of whose members developed new planetary models whose influence on **Nicolaus Copernicus** has been clearly demonstrated. These models were meant to deal with the criticisms of Ptolemaic astronomy that had been previously set forth in Egypt (11th century) and al-Andalus (12th century). Ibn Abī al-Shukr also compiled Arabic versions of the most important Greek trigonometric treatises and made some useful innovations.

We know little of Ibn Abī al-Shukr’s early life, but his name suggests an Andalusī origin. It is also known that he studied the religious law of the Mālikī School, a school with a wide influence in al-Andalus. As for the eastern part of his life, we know that he lived in Damascus at least until the year 1258, where he is believed to have written the *Tāj al-azyāj* (The crown of astronomical handbooks), or at least the first version of it. Furthermore, he himself told **Bar Hebraeus** that his knowledge of astrology had saved his life when the Mongols invaded Damascus (*circa* 1258). According to Ibn al-Fuwaṭī, the librarian of the Marāgha Observatory, he joined **Naṣīr al-Dīn al-Ṭūsī**’s team at Marāgha at an unknown date, though clearly before 1262, the year that Ibn Abī al-Shukr himself mentions as the date of some astronomical observations that he conducted at the Marāgha Observatory. In fact, he probably joined the team before 1260, because at that date his *Taḥrīr al-uṣūl* (Recension of Euclid’s *Elements*) was being copied in Marāgha, perhaps by his own hand. According to the sources, Ibn Abī al-Shukr worked for some 20 years in Marāgha, and in 1275 he composed his second *zīj*, entitled *Adwār al-anwār madā al-duhūr wa-’l-akwār* in which he introduced the results of the astronomical observations he carried out in Marāgha.

Ibn Abī al-Shukr was a good mathematician, and his writings on trigonometry contain certain original elements. After traveling at least once to Baghdad with Naṣīr al-Dīn al-Ṭūsī’s son, he went back to Marāgha, where he devoted his life to teaching. Ibn Abī al-Shukr died in Marāgha, where he enjoyed an excellent reputation.

Ibn Abī al-Shukr’s work deals with three different subjects: astronomy, astrology, and mathematics (geometry and trigonometry). Most of his work has not yet been studied, so for the moment no definitive account of his contribution to Islamic science is possible.

Ibn Abī al-Shukr’s astrological works are mainly devoted to horoscopes and planetary conjunctions used to tell the future.

His known works on astronomy include three *zīj*es; three commentaries on the *Almagest*; a description of the construction and use of the astrolabe (*Tasṭīḥ al-asṭurlāb*); a description of the geometrical methods used to determine the meridian line, the rising amplitude, and the revolution of the sphere (*Maqāla fī istikhrāj taˁdīl al-nahār wa saˁat al-mashriq wa-’l-dā’ir min al-falak bi-ṭarīq al-handasa*); and a chronological work on the Chinese and Uighur calendars (*Risālat al-Khaṭā wa-’l-īghūr*). Hūlāgu and his brother Qubilai, rulers of Marāgha and Beijing, respectively, were both interested in astronomy and had their astronomers translate works on the subject from Arabic and Persian into Chinese.

Two of the *zījes*, the *Tāj al-azyāj wa-ghunyat al-muḥtāj* (= *al-muṣaḥḥaḥ bi-adwār al-anwār maˁa al-raṣad wa-’l-iˁtibār*, according to Escorial MS 932) and the *Adwār al-anwār madā al-duhūr wa-’l-akwār*, represent a break in the Andalusī–Maghribī tradition. The only Andalusī materials preserved are the tables of geographical coordinates. According to the author, in the second *zīj* he included the results of the astronomical observations he carried out in Marāgha. However, we find some of these results in the Maghribī copies of the *Tāj* for which, according to the title of one of the manuscripts, the *Adwār* was used. Echoes of these *zījes*, especially of the *Tāj*, resonate not only in al-Maghrib but also in Hebrew and Latin European sources, especially in Barcelona. One example is the abandonment of the trepidation models, which are found in all the Andalusī and Maghribī *zījes*, and the proposal of a new parameter for precession. The only extant copy of the third *zīj*, entitled *ˁUmdat al-ḥāsib wa-ghunyat al-ṭālib* and compiled in Marāgha (*circa* 1262) after the *Tāj* and before the *Adwār*, is a mixture of different *zījes* and has nothing to do with Ibn Abī al-Shukr’s work.

With regard to the *Almagest*, he wrote the *Talkhīṣ al-Majisṭī* (Compendium of the *Almagest*), based on his observations carried out between the years 1264 and 1275; the *Khulāṣat al-Majisṭī* (Summary of the *Almagest*), different from the *Talkhīṣ*; and the *Muqaddimāt tataˁallaq bi-ḥarakāt al-kawākib* (Prolegomena on the motion of the stars), which contains five geometric premises on the planetary motions in the *Almagest*.

Mercè Comes

Alternate name

Ab**ī** al-Shukr

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Ibn al-Aˁlam: ˁAlī ibn al-Ḥusayn Abū al-Qāsim al-ˁAlawī al-Sharīf al-Ḥusaynī

Died **possibly Baghdad, (Iraq), 985**

Ibn al-Aˁlam composed a *zīj* (astronomical handbook with tables) that later influenced astronomy in Iraq and Iran, especially **Naṣīr al-Dīn al-Ṭūsī**'s *īlkhānī Zīj* (13th century), and in Byzantium. He was also reported to have practiced astrology under the patronage of the Būyid ruler of Baghdad ˁAḍud al-Dawla (978–983) and to have cultivated musical theory. Very little is known about Ibn al-Aˁlam's life and work. His *zīj*, unfortunately lost, is only known by later references in other astronomical works. One of the names given to this work, *al-Zīj al-ˁAḍudī*, derives from the name of his patron. It was also known as *al-Zīj al-Sharīf*, from the name of the author, and *al-Zīj al-Baghdādī*, which either refers to his place of residence or may indicate that the original tables were based on the prime meridian of Baghdad.

Ibn al-Aˁlam's work attracted significant interest, mainly because of the observations attributed to him; the values from his *zīj* are reported in several sources in Arabic, Persian, and Greek. Recent analyses of the quoted planetary parameters for epoch positions, mean motions, and equations indicate that Ibn al-Aˁlam's planetary tables were formed on the basis of a review and consolidation of earlier observations rather than by his own observations. There is, though, no information available on other materials typically found in this kind of work, such as tables for calendars, geographical coordinates, fixed stars, or trigonometric and spherical functions.

Regarding the influence of the work, Greek sources mention Ibn al-Aˁlam under the name of Alim; there is evidence for the existence of a Byzantine version of his tables, adapted to the Byzantine calendar and, probably, to the meridian of Constantinople, made by the year 1032 and used one century later for casting a pair of horoscopes for the years 1153 and 1162. A number of Persian and Arabic sources reveal that Ibn al-Aˁlam's tables were being used from his own time until the 14th century. In *al-Zīj al-Ḥākimī*, the Egyptian astronomer **Ibn Yūnus** (*circa* 990) stated that Ibn al-Aˁlam made observations with instruments constructed by him, and he took the motion of the mean Sun and the rate of precession from Ibn al-Aˁlam's tables. The Persian astronomer **Shams al-Munajjim Muḥammad ibn ˁAlī al-Wābkanawī** reported in his *zīj* (*circa* 1320) that in the *Zīj-i īlkhānī*, the group of astronomers working at the Marāgha Observatory under Ṭūsī did not apply their own observations, but used the mean motions of Ibn al-Aˁlam. Indeed, an analysis of the *Zīj-i īlkhānī* shows that the underlying parameters used for the solar, lunar, and planetary tables were all taken from Ibn al-Aˁlam and Ibn Yūnus. Finally, the Persian *Zīj-i Ashrafī*, written *circa* 1310 by Sayf-i Munajjim Muḥammad ibn Abī ˁAbd Allāh Sanjar al-Kāmilī, preserves the values of Ibn al-Aˁlam for the radices, the equations, and the apogees.

Josep Casulleras

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Ibn Bājja: Abū Bakr Muḥammad ibn Yaḥyā ibn al-Ṣā'igh al-Tujībī al-Andalusī al-Saraqusṭī

Born **Saragossa, (Spain), last third of the 11th century**
Died **Fez, (Morocco), June or July 1139**

Ibn Bājja, one of the most important philosophers of Muslim Spain, was in the forefront of the 12th-century Andalusian movement to criticize and replace Ptolemaic astronomy based on Aristotelian principles. In addition to astronomy, he was also active in other scientific disciplines, such as mathematics, botany, pharmacology, and medicine. Ibn Bājja learned philosophy and other sciences in an environment that was deeply influenced by the court, ruled at that time by the Banū Hūd dynasty whose kings were patrons of science and scientists. Under their protection, Saragossa became an important center of both philosophical and mathematical studies. Ibn Bājja also mastered poetry and other disciplines that were based on the Arabic language and Islamic teachings. The Banū Hūd were ousted from Saragossa in 1110, but Ibn Bājja was employed by the city's new Almoravid governor, Ibn Tīfalwīt, whom he served for 3 years, though the exact dates are not known. The governor sent him as ambassador to ˁImād al-Dawla ibn Hūd, the former ruler of Saragossa who had established his court in Rueda de Jalón. The latter imprisoned him for several months. Ibn Bājja returned to Saragossa but soon left, perhaps because of the death of his protector Ibn Tīfalwīt (1117). The city would be occupied by the Christians in the following year. From that point on, his life became a long pilgrimage that took him to several cities in Muslim Spain and North Africa – Xàtiva, Almeria Granada, Oran, and perhaps Seville – though he never settled. According to some sources, Ibn Bājja held the post of minister to Yaḥyā ibn Yūsuf ibn Tāshifīn, governor of Fez, though some scholars disagree. Nonetheless, this episode, together with his period in the service of Ibn Tīfalwīt, is proof of his relationship with the Almoravid dynasty in spite of his scientific and philosophical career. The Almoravids based their legitimacy on religious observance and were therefore hostile to philosophy and other disciplines that could challenge their concept of orthodoxy. Ibn Bājja was imprisoned at least once by the Almoravids in Xàtiva for heterodoxy, but, apparently, the episode had no further consequences. It appears that he spent the last period of his life far from the court, occupied in his intellectual work and earning a living as a physician. However, the many challenges he had to confront during his life seem to have interfered with his intellectual work, as we find a large number of short, fragmentary, and incomplete treatises. The story of Ibn Bājja's death bears witness to the turbulence of the times, as he is said to have been poisoned by order of Abū al-ˁAlā' Zuhr, a member of the most important dynasty of court physicians in Muslim Spain, whether or not the story is true, other sources seem to attest to the enmity between the two scientists, an enmity that combined personal rivalry and religious considerations.

Ibn Bājja's work in natural philosophy has certain implications for the history of astronomy. In his commentaries on **Aristotle**'s *Physics* he accepted – diverging from Aristotle, and supporting **John Philoponus** – the possibility of motion in the void or in a medium that does not exert resistance, as happens in the celestial bodies, thus applying the physical principles of the sublunary world to the heavens. These ideas were echoed by European Scholastics, and from there may have influenced **Galileo Galilei**. However, this conception of dynamics cannot be traced, for the moment, in Ibn Bājja's astronomical thought.

The importance of Ibn Bājja's astronomy lies in the fact that he seems to have been the first of the Andalusians to develop a criticism of **Ptolemy** based on philosophical tenets (the others being **Ibn Ṭufayl**, **Ibn Rushd**, and **Biṭrūjī**). They wished to formulate a cosmos according to Aristotelian principles (uniform and circular motions centered on the Earth) in which planetary models had no need of eccentrics and epicycles. According to **Maimonides** in *The Guide of the Perplexed*, Ibn Bājja accepted eccentrics but not epicycles. However, a deeper study of his extant works has revealed two important, and hitherto unremarked, facts: On the one hand, Ibn Bājja must have had a profound knowledge of mathematical astronomy (consistent with the fact that he was a mathematician), and the information found in a range of sources, including his own letters, reveal that he observed an occultation of Jupiter by Mars, observed solar transits of Venus and Mercury (seemingly a confusion with sunspots), and predicted a lunar eclipse. On the other hand, Ibn Bājja must originally have been a follower of Ptolemy. In a letter addressed to Abū Jaˁfar Yūsuf ibn Ḥasdāy, he attacks **Ibn al-Haytham**, one of the most important mathematical astronomers who criticized Ptolemy, arguing that Ibn al-Haytham did not understand Ptolemy's models for Mercury and Venus, something that is fairly clear in the case of Mercury. Again on the subject of Mercury, he disagrees with the Andalusian astronomer **Zarqālī**, who formulated some alternative models to Ptolemy. Besides, in his commentary to Aristotle's *Physics*, Ibn Bājja introduces a digression following Philoponus in which he accepts the existence of epicycles. However, a short and incomplete treatise has survived entitled *Kalām fī al-hay'a* (Discourse on cosmology) that criticizes Ptolemy's method. Here, on the basis of Aristotelian logic, Ibn Bājja tackles the problem of the relationship between what the astronomer can observe and the underlying reality and argues that the planetary models of the Ptolemaic astronomers do not fit the tenets of Aristotelian scientific method.

Miquel Forcada

Alternate names

Avempace
Bājja

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Ibn al-Bannāʾ: Abū al-ˁAbbās Aḥmad ibn Muḥammad ibn ˁUthmān al-Azdī al-Marrākushī

Born **Marrakech, (Morocco), 29 or 30 December 1256**
Died **31 July 1321**

Ibn al-Bannāʾ al-Marrākushī, mathematician and astronomer, was born in Marrakech where he studied a variety of subjects, reportedly with at least 17 masters. However, he frequently went to Aghmāt, near Marrakech, where he was a student of Abū ˁAbd Allāh al-Hazmīrī (died: 1279); it may have been due to his influence that Ibn al-Bannāʾ became interested in both astronomy and astrology, and gained the reputation of being a Sufi. Ibn al-Bannāʾ was probably a practicing astrologer in the service of the Marīnid sultan Abū Saˁīd (reigned: 1309–1331), and he is said to have predicted the exact circumstances of the latter's death, which took place some 10 years after his own. He was dedicated to his teaching, which took place both in the great mosque of Marrakech and in his own home, and he had at least eight disciples.

The catalog of Ibn al-Bannāʾ's works comprises about a 100 titles, out of which some 50 are dedicated to mathematics and astronomy (including astrology), but the list also includes Quranic studies, theology (*uṣūl al-dīn*), logic, law (*fiqh*), rhetoric, prosody, Sufism, the division of inheritances (*farā'iḍ*), weights and measures, measurement of surfaces (*misāḥa*), talismanic magic, and medicine. His reputation is based mainly on his mathematical works (especially arithmetic and algebra); he has been considered the last creative mathematician in the Maghrib, meaning that he approached new problems and gave original solutions. His works were extremely popular, and inspired an enormous number of commentaries, which were still being written until the beginning of the 20th century.

In the field of astronomy, Ibn al-Bannāʾ is a clear follower of the Andalusian tradition represented by the Toledan astronomer **Zārqālī**, whose works reached him either directly or indirectly. He wrote short works on the two varieties of universal astrolabes (*shakkāziyya* and *zarqāliyya*) designed by this author, as well as an astronomical handbook with tables (*zīj*) derived ultimately from the research of Zārqālī. The title of this *zīj* is *Minhāj al-ṭālib fī taˁdīl al-kawākib* (The student's method for the computation of planetary positions), and it became extremely popular in the Maghrib. There were at least three commentaries, and it was still in use in the 19th century. The direct source used by Ibn al-Bannāʾ was the unfinished *zīj* of **Ibn Isḥāq**, which seems to have exercised the predominant influence in Maghribī astronomy during the 13th and 14th centuries. Ibn al-Bannāʾs *Minhāj* contains a selection of Ibn Isḥāq's tables accompanied by a collection of canons that are easy to understand, which makes the *zīj* accessible for the computation of planetary longitudes. This is accompanied by some modifications of the structure of the tables, designed to make calculations easier. Both the tables of the solar equation and those of the planetary and lunar equations of the center are "displaced" (a constant is added to every entry of the table in order to avoid negative values), a technique used for the first time in the Maghrib. Although Ibn al-Bannāʾ used the standard structure, derived from the *Handy Tables*, for the tables of the equation of the anomaly of Mars, Venus, and Mercury, he changed them entirely in the cases of Jupiter and Saturn – planets that have small epicycles – for which the equation of the anomaly is calculated in the same way as for the Moon.

The *Minhāj* is not the only *zīj* produced by Ibn al-Bannāʾ, who prepared a summary of it entitled *al-Yasāra fī taqwīm al-kawākib al-sayyāra* (The simple method for the computation of planetary positions). This smallest possible form of a *zīj*, concerned mainly with the computation of planetary longitudes, was prepared most likely for popular astrologers who, apparently, were expected to learn the very short text of his canons by heart. The very few numerical tables are also simplified as much as possible and, in the case of the Moon, we go back to a simple model with only one inequality and a maximum equation of 5° (either a rounding of the standard Indian value 4° 56′ or of **Ptolemy**'s first lunar inequality of 5° 1′). The *Yasāra* met with some success, and Ibn al-Bannāʾ himself summarized it even further in his *al-Ishāra fī ikhtiṣār al-Yasāra* (How to summarize the *Yasāra*). The *Yasāra* was also the subject of commentaries, adaptations, and corrections of defects such as that written by Ibn Qunfudh al-Qusanṭīnī (1339–1407).

It is evident from his writings that Ibn al-Bannāʾ wrote mainly for his students and always tried to be extremely brief and concise. He was also interested in the practical applications of his knowledge. For example, he wrote on the applications of geometry to land surveying, on the use of arithmetic and algebra to solve problems of partitioning inheritances, on weights and measures, and on the procedures for calculating with the *Rūmī* ciphers (apparently derived from the Greek cursive alphanumerical system of numeration), which were often used in Maghribī legal documents. In a field more related to astronomy, Ibn al-Bannāʾ wrote the *Kitāb fī al-anwāʾ*, a book on the pre-Islamic Arabic calendar system and meteorological predictor based on the heliacal risings and acronychal settings. He was also interested in the problems of timekeeping applied to Islamic worship and wrote short works, such as his *Qānūn fī maˁrifat al-awqāt bi'l-ḥisāb* (Rules to know time by calculation [*i. e.*, without instruments]), which seems to have been directed toward the elementary astronomical education of muezzins and imams who were responsible for the determination of prayer times and for the fixing of the beginning of lunar months. Furthermore, Ibn al-Bannāʾ wrote a short report on the visibility of the New Moon of Ramaḍān of the year 1301 due to the fact that the people of Fez had begun their fasting 1 day earlier than those of Marrakech and Tlemcen. A similar practical/religious concern appears in his two short texts on the *qibla* (direction toward Mecca): Ibn al-Bannāʾs contemporaries were worried about the problem posed by the different orientations of mosques, and he tried to ease their consciences by stating that all of them had a correct orientation, which should not be changed in as much as they had been established with due intellectual effort (*ijtihād*). Surprisingly enough, this astronomer rejected the use not only of the imprecise methods of folk astronomy but also of those of spherical astronomy, which had given exact solutions to the problem since the 9th century. He gave two reasons: The results obtained were not necessarily precise, for the differences in geographical longitude between Mecca and other Islamic cities were not reliably known; and the knowledge required could not be expected from a lay Muslim.

A difficult problem is that of Ibn al-Bannāʾs attitude toward astrology. It has been well established that he had been interested in the subject during the early stages of his scholarly life and that he wrote a number of short astrological works that have little originality and a very limited interest. They do, though, bear witness to the fact that he is following an Andalusian–Maghribī tradition that has certain characteristics different from those of the Eastern Islamic one. On the other hand, it seems that he wrote a nonextant work entitled *Radd ˁalā al-aḥkām al-nujūmiyya* (Refutation of astrological judgments), which seems to have been written in the second period of his scholarly life (1290–1301). It is difficult to establish clearly whether Ibn al-Bannāʾ lost his faith in the scientific character of astrology since the *Minhāj* (apparently written during the same period) describes techniques of mathematical astrology and the Marīnid sultan Abū Saˁīd reportedly consulted him as an astrologer.

Julio Samsó

Alternate name

al-Bannāʾ

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Ibn Bāṣo: Abū ˁAlī al-Ḥusayn ibn Abī Jaˁfar Aḥmad ibn Yūsuf ibn Bāṣo

Died **Granada, (Spain), 1316**

Ibn Bāṣo was the head of the timekeepers (*raʾīs al-muwaqqitīn*) in the Great Mosque of Granada. He was also a master of the science of calculation, highly skilled in astronomical observation, an inventor, and the author of several treatises.

Little is known about Ibn Bāṣo's life. He was probably one of the two Ibn Bāṣos mentioned by Ibn al-Khaṭīb in his biographical work, *al-Iḥāṭa*, although this author gives his name as Abū ˁAlī Ḥasan ibn Muḥammad ibn Bāṣo.

According to Ibn al-Khaṭīb, Ibn Bāṣo was from the *Sharq al-Andalus*, the eastern part of the Iberian Peninsula. The fact that he was the head of the timekeepers (*raʾīs al-muwaqqitīn*) in the Great Mosque of Granada is extremely interesting, because it suggests that the mosque had an organized, institutionalized group devoted to timekeeping.

Two of Ibn Bāṣo's written texts are preserved. One of them is the *Risālat al-ṣafīḥa al-jāmiˁa li-jamīˁ al-ˁurūḍ* (Treatise on the universal plate for all latitudes). The other is the *Risālat al-ṣafīḥa al-mujayyaba dhāt al-awtār* (Treatise on the plate of sines provided with chords). In both texts the author is named as Abū ˁAlī al-Ḥusayn ibn Abī Jaˁfar Aḥmad ibn Yūsuf ibn Bāṣo and is described as *amīn awqāt al-ṣalawāt* (keeper of the times of prayers) and *imām al-mu'adhdhinīn* (leader of the muezzins).

The differences in name between what one finds in Ibn al-Khaṭīb's biography and in the treatises themselves have led some specialists (such as George Sarton) to suggest that there were two Ibn Bāṣos. However, later investigators—H. P. J. Renaud, among others—proposed that the treatises were the work of one and the same person, adducing that differences in the name were frequent in Arabic biographies.

The first treatise, the *Risālat al-ṣafīḥa al-jāmiʿa li-jamīʿ al-ʿurūḍ*, was compiled in the year 1273 and was devoted to the description of the use of a universal plate for all latitudes. The author states that he was the inventor of the instrument. The treatise suggests that the author was aware of the work of previous astronomers in the Muslim world, especially of the work carried out in the 11th century in Andalusia. There are also similarities with some treatises of *mīqāt* written in 13th-century Egypt. The astrolabe plate is one in which the horizontal coordinates have been omitted, and the horizons have been multiplied in order to serve for different latitudes. It corresponds to the type of instrument usually called *ṣafīḥa āfāqiyya*, "plate of horizons," and it is similar to a conventional astrolabe plate. The fact that this plate does not have horizontal coordinates and is limited to the projection of a set of horizons has led specialists to think that it was used only for simple operations. However, a study of the treatise shows that the instrument was as versatile as any other astrolabe plate, although it is difficult to use because of the number of lines in its layout and because of the complicated procedures that the user would need to know. In this treatise the author is not seeking great precision: the values are clearly rounded. It was probably the didactic potential of the plate that the author was most interested in exploiting. Indeed, using the plate would have provided a very useful exercise for anybody who wanted to become familiar with the celestial spheres and their properties. This plate seems to have been designed to carry out all types of speculative calculation: its use in extreme northern latitudes or in latitudes south of the equator cannot be considered a practical application. Nevertheless, the possibility of using this plate as a southern astrolabe plate, in spite of the fact that it is designed for the Northern Hemisphere and is meant to fit in a northern astrolabe, is its most original characteristic and thus can be considered a forerunner of later instruments.

Ibn Bāṣo's work became well known. There are a number of summaries of the treatise, most of them of Maghribi origin, and the projection was included in several instruments still preserved in Andalusia, North Africa, and also in the Islamic East as is the case of instruments constructed by **Mizzī** in Damascus and Allāh-Dād in Lahore. Although universal instruments of this type had already been described by earlier astronomers such as **Sijzī** or **Bīrūnī**, they do not seem to have been built until the time of Ibn Bāṣo, when, starting in the 14th century, they seem to have proliferated in North Africa and the Muslim East as well as in Europe.

The other treatise written by Ibn Bāṣo that is still preserved, the *Risālat al-ṣafīḥa al-mujayyaba dhāt al-awtār*, is contained in manuscript 5550 of the National Library of Tunisia. The introduction of this treatise presents abundant similarities to that of the previous one. In this treatise, the author describes the use of a trigonometric plate of his invention that can perform all kinds of calculations of spherical astronomy.

Emilia Calvo

Alternate name

Baṣo

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Ibn ʿEzra: Abraham ibn ʿEzra

Born **Tudela, (Navarra, Spain), *circa* 1089**
Died **Rome, (Italy), or possibly Palestine, *circa* 1167**

Abraham ibn ʿEzra was a poet, grammarian, biblical exegete, philosopher, astronomer, astrologer, and physician. He lived in Spain until 1140 and then left Spain for a period of extensive wandering in Lucca, Mantua, Verona, Provence, London, Narbonne, and finally Rome. It was during the latter period that most of his works were composed. His wanderings forced him to write in Hebrew as well as in Latin, a fact that perhaps saved his works from oblivion. Like his teacher Abū al-Barakāt, his son Isaac converted to Islam.

Ibn ˁEzra is best known for his biblical commentaries, which are written in an elegant Hebrew, replete with puns and word plans. These commentaries were commenced in Rome when he was already 64. Ibn ˁEzra was the first Jewish author to interpret a significant number of biblical events in an astrological way and to explain certain commandments as defenses against the pernicious influence of the stars.

Because of his constantly alluding to "secrets" in these commentaries based on astrological doctrines, Ibn ˁEzra's works inspired numerous supercommentaries. Ibn ˁEzra himself claimed that only the individual schooled in astrology, astronomy, or mathematics would understand these commentaries properly. Perhaps the most famous commentator upon Ibn ˁEzra was Spinoza, who adduced "Aben Ezra, a man of enlightened intelligence and no small learning," in support of his own contention that Moses could not have written the Pentateuch. Although Ibn ˁEzra did not write any specifically philosophical works, he was strongly influenced by the Jewish Neoplatonist philosopher Solomon ibn Gabirol, and his works contain much Neoplatonic material.

Although Ibn ˁEzra was one of the foremost transmitters of Arabic scientific knowledge to the West, most of his scientific works are extant in manuscript only. Interestingly, most of his works appear in two or more versions; most scholars agree that in as much as Ibn ˁEzra was an itinerant scholar wandering from city to city, he would write new versions for each group of patrons he encountered.

The first group of treatises is devoted to teaching skills related primarily to astronomy and mathematics, as well as the use of scientific tools and instruments. The major works in this group are *Sefer ha-mispar* (The book of the number), designed to be a basic textbook in mathematics; *Sefer taˁamei ha-luhot* (The book of the reasons behind the astronomical tables), a treatise written in four different versions (two in Hebrew and two in Latin) to provide astronomical and astrological knowledge to persons interested in using astronomical tables; *Keli ha-nehoshet* (The instrument of brass, *i. e.*, the astrolabe), a technical manual, written in three different Hebrew versions as well as a Latin version, designed to teach the astronomical and astrological uses of the astrolabe; *Sefer ha-ˁibbur* (The book of intercalation), written in two versions, designed to establish the Jewish calendar and explain its fundamentals; and, finally, *Sefer ha-ʾehad* (The book on the unit), a short mathematical treatise devoted to the attributes of the numbers.

The second group of treatises comprises astrological works exclusively and includes both astrological textbooks and a series of astrological works that deal with the various branches of astrology. In addition to these treatises, Ibn ˁEzra translated into Hebrew a no longer extant Arabic scientific treatise, Ibn al-Muthannā's *Commentary on the Astronomical Tables of al-Khwārizmī*. This work includes Ibn ˁEzra's introductory assessment of the transmission of Hindu and Greek astronomy to the Arabic sciences.

Because Ibn ˁEzra was one of the first Hebrew scholars to write on scientific subjects in Hebrew, he had to invent many Hebrew terms to represent the technical terminology of Arabic. For example, he introduced terms for the center of a circle, for the sine, and for the diagonal of a rectangle. He describes his own research as *hakmei ha-mazzalot* (science of the zodiacal signs), a term he uses often to refer to a number of branches of science: astrology, mathematics, astronomy, and the regulation of the calendar. In as much as the purpose of these works was primarily to educate and introduce scientific findings to a lay audience, they serve as an excellent source of learning about scientific texts available in 12th-century Spain.

As noted by Shlomo Sela, one of Ibn ˁEzra's main aims was to "convey the basic features of Ptolemaic science, astronomical as well as astrological, as it was transformed by the Arabic sciences, especially in al-Andalus" (Sela, 2000, p. 168). Thus, for example, his best-known work, *Beginning of Wisdom*, functions as an introductory astrological textbook and deals with the zodiacal constellations and planets, their astrological characteristics, and more technical aspects of astrology. Ibn ˁEzra's star list appears as a section of his work *The Astrolabe*. The list is given in the form of a paragraph, in which the coordinates are given in Hebrew alphabetic numerals, and the Arabic names are transliterated into Hebrew characters. As Bernard Goldstein has pointed out, many of the discrepancies between Ibn ˁEzra's star positions and those in the Greek text of the *Almagest* can be traced to the Arabic versions of the *Almagest*. In his translation of Ibn al-Muthannā's *Commentary*, Ibn ˁEzra describes the early stages of astronomy among the Arabs, listing a number of prominent astronomers whose works he consulted. The Hebrew versions of Ibn al-Muthannā's commentary have been useful for interpreting a set of canons for tables with Toledo as the meridian preserved in a Latin manuscript.

According to John North, Abraham ibn ˁEzra was the earliest scholar to record one of the seven methods for the setting up of the astrological houses. This method was used, for example, by **Gersonides** who made use of Ibn ˁEzra's *Book of the World* in his prognostication of 1345.

In as much as Abraham Ibn ˁEzra's works were widely copied in Hebrew and translated into European languages, he was responsible for the availability of much Arabic science in Hebrew and Latin, and he helped to spread the new Hebrew astronomical literature throughout Europe.

Tamar M. Rudavsky

Alternate name

Ezra

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Ibn al-Hā'im: Abū Muḥammad ʿAbd al-Ḥaqq al-Ghāfiqī al-Ishbīlī

Flourished **Seville, (Spain), thirteenth century**

In addition to his own astronomical accomplishments, Ibn al-Hā'im provides important historical information on earlier astronomers in al-Andalus. All we know of his life is that he came from Seville, and that he probably worked in North Africa under the Almohad dynasty.

At the beginning of the 13th century (1204–1205), Ibn al-Hā'im composed a single work entitled *al-Zīj al-kāmil fī al-taʿālīm*, which he dedicated to the caliph Abū ʿAbd Allāh Muḥammad al-Nāṣir, who reigned from 1195 to 1213. It is a relatively long text, consisting of an introduction and seven books (*maqālāt*). The text can be considered a *zīj* (astronomical handbook) on the basis of its structure and contents, even though it does not include numerical tables; it contains only the canons giving calculating procedures together with geometrical proofs. Ibn al-Hā'im was a good mathematician and was familiar with the new trigonometry introduced in al-Andalus by **Ibn Muʿādh** (11th century) and extended by **Jābir ibn Aflaḥ** (12th century).

Al-Zīj al-kāmil is important because it describes the astronomy practiced in al-Andalus and the Maghreb at the beginning of the 13th century and informs us of the Toledan observations (*al-arṣād al-Ṭulayṭuliyya*) and the activities of the Toledan astronomers (*al-jamāʿa al-Ṭulayṭuliyya*) working under the patronage of **Ṣāʿid al-Andalusī** in the 11th century. The work also gives us historical data on the Andalusian astronomer **Zarqālī**, who seems to have had a considerable influence on Ibn al-Hā'im's theories and models. In the introduction to his book, Ibn al-Hā'im criticizes two books by Zarqālī's student **Ibn al-Kammād**: *al-Kawr ʿalā al-dawr* and *al-Muqtabas*.

In *al-Zīj al-kāmil*, Ibn al-Hā'im seems to describe all he knows about the trepidation and obliquity of the ecliptic models developed in al-Andalus, especially Zarqālī's third model, in which variable precession becomes independent of the oscillation of the obliquity of the ecliptic. Trepidation has to be taken into account in most of the calculations and procedures presented in the book. He provides a description and a geometrical demonstration, explains how to use the tables, and also presents the spherical trigonometrical formulae involved. Ibn al-Hā'im attributes the *Risālat al-iqbāl wa-'l-ibdār* (Epistle on accession and recession) to the 11th century astrologer Abū Marwān al-Istijjī, and preserves some data from that book.

Since Zarqālī's treatise on the Sun (*Fī sanat al-shams*, On the solar year) is only known through secondary works, Ibn al-Hā'im's text is a useful additional source. Ibn al-Hā'im follows Zarqālī in establishing and calculating the basic elements of solar theory. He gives a longitude of the solar apogee of 85° 49′, which coincides with the value determined by Zarqālī in his observations performed in 1074/1075, as documented in the Latin tradition of Bernard of Verdun. To calculate the solar equation and the true longitude of the Sun, Ibn al-Hā'im follows Zarqālī's solar model of variable eccentricity. Ibn al-Hā'im describes three different types of year: tropical, sidereal, and anomalistic. His classification is practically identical to the one given by Zarqālī himself. Ibn al-Hā'im devotes great attention to the computation of the anomalistic year which, in his opinion, is the basis for obtaining the other two types of year; since its value is fixed, it is the one that should be used to obtain mean motions and to carry out astronomical calculations.

As for lunar theory, the *zīj* deals with two aspects of the theory of the Moon: the computation of its longitude, and the computation of its latitude. Ibn al-Hā'im proposes two corrections to the standard Ptolemaic lunar theory. The first is an attempt to correct the theory of lunar longitude. The correction is ascribed to a lost astronomical work of Zarqālī, which Ibn al-Hā'im had read in a manuscript written by the Toledan astronomer himself. It seems to imply the existence of a lunar equant point that rotates with the motion of the solar apogee. We do not know to what extent the generalization of the correction of the Ptolemaic lunar model is due to Zarqālī himself or is the result of Ibn al-Hā'im's interpretation of his work. In any case, this model met with some success, for we find the same correction in later *zīj*es although restricted to the calculation of eclipses and the New Moon. The second correction is a peculiar one: It is a correction of the computation of the lunar latitude that is directly related to a practice in the calculation of longitudes that had been standard among Muslim astronomers since the *Mumtaḥan zīj* of **Yaḥyā ibn Abī Manṣūr**, though with Ibn al-Hā'im there is a change of approach. He believes that his lunar model gives ecliptic longitudes, that Yaḥyā’s reduction to the ecliptic is unnecessary for the computation of longitudes, and that an inverse reduction to the lunar orbit should be operated to calculate latitudes. The results of Ibn al-Hāʾim’s model are different from **Ptolemy**’s, and also from those obtained by Yaḥyā ibn Abī Manṣūr and his followers.

Roser Puig

Alternate name

al-Hāʾim

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Ibn al-Haytham: Abū ʿAlī al-Ḥasan ibn al-Ḥasan

Born **Basra, (Iraq), 965**
Died **Cairo, (Egypt), *circa* 1040**

Ibn al-Haytham (often referred to in the literature as Alhazen, the Latin version of al-Ḥasan) was one of the most important and influential figures in the history of science. He wrote on topics that included logic, ethics, politics, poetry, music, and theology (*kalām*), and produced summaries of **Aristotle** and Galen. His extant works are mostly on mathematics, optics, and astronomy. As a young man, Ibn al-Haytham moved to Egypt from Iraq and was involved in an abortive engineering project in Egypt on regulating the flow of the Nile. The sources do not agree on the details of the story; however, it is clear that after this brief try at government work, Ibn al-Haytham chose a life of quiet scholarship. He earned his living copying scientific manuscripts, and carried out extensive research and correspondence in philosophy and the sciences.

In his youth Ibn al-Haytham inquired into the different religions and came to the conclusion that the truth is one. This fundamental insight of gaining favor with God by seeking knowledge of the truth underlies some of his most important scientific activity. Specifically with regard to astronomy, Ibn al-Haytham was troubled by inconsistencies in the treatment of problems of interest to astronomy and two other disciplines, natural philosophy and optics. His most repercussive writings critically examine the issues and propose solutions.

At least since Aristotle, it has been taken for a fact that the motions of the celestial bodies are uniform and circular, and that the stars are embedded within a set of concentric spheres. However, astronomy had progressed much in the intervening centuries; in particular, the *Almagest*, **Ptolemy**’s landmark text, had set out a theory far more detailed and complex than anything Aristotle had proposed. True, Ptolemy himself had tried to give a physical account in his *Planetary Hypotheses*. However, no one was quite sure how all the pieces fit together. Moreover, some of the mathematical devices that Ptolemy had employed, for example, the equant or lunar prosneusis, were in direct violation of the principle of uniform circular motion about a fixed center.

Ibn al-Haytham addressed these issues in a number of his writings. In his *al-Shukūk ʿalā Baṭlamyūs* (Doubts concerning Ptolemy), a thoroughgoing critique of the *Almagest, Planetary Hypotheses*, and *Optics*, he showed in great detail where and how Ptolemy had violated the principles of natural philosophy. An early monograph, which does not survive but which is mentioned in a later defense of his views and is summarized by **Naṣīr al-Dīn al-Ṭūsī**, attempts to provide a physical solution for one of the knottiest problems, the motion called *iltifāf*, which was produced by Ptolemy’s models for the motion in latitude of the planets.

Fī Hay’at al-ʿālam (On the configuration of the world) is perhaps Ibn al-Haytham’s most ambitious effort in this area of research; it certainly was his most influential astronomical writing. Like other books of the genre known as *hay’a* (a cosmography of the Universe), Ibn al-Haytham’s treatise explains basic astronomical concepts (*e. g.*, longitude, latitude, and altitude) and discusses mathematical geography. This work proposes to match the geometry of mathematical astronomy to the three-dimensional picture endorsed by natural philosophy, so that the reader will be aware of the identity between the two systems. However, Ibn al-Haytham does this only schematically. That is to say, in each of the chapters devoted to the planets, he first describes the three-dimensional orbs, moving inward from the planet to the center of the Earth; this is the depiction of natural philosophy. Ibn al-Haytham then reverses this description, this time showing how these orbs are in fact the intersections of the three-dimensional bodies with the planes of the circles produced by either the planet or devices such as the center of the epicycle; these are the geometrical constructs of the astronomers. Note that the outstanding problems of celestial physics—those elucidated in detail in the *Doubts*—are left unresolved. Nonetheless, *On the Configuration* does give a consistent report in which both the philosophical and the mathematical accounts harmonize. As noted above, the book was widely repercussive, especially in translation; two different Latin translations are extant, and no less than five different Hebrew translations have been identified.

The divergences between the physical and the mathematical accounts were fundamental, and their resolution required a rethinking of astronomical modeling. Ibn al-Haytham provided only basic direction in this matter; however, his influence is felt on later people, most notably Naṣīr al-Dīn al-Ṭūsī, who worked toward a fuller resolution of the issues.

The conflicts between astronomy and optics were far less serious, affecting only some specific problems. The so called Moon illusion, *i. e.*, the apparent enlargement of celestial bodies and the distances between them when they lie low on the horizon, occupied Ibn al-Haytham's attention throughout his career. In his youthful commentary to the *Almagest*, he endorsed and even provided with "proof" Ptolemy's remarks that the enlargement is produced by refraction through the Earth's "vapors" (*i. e.*, atmosphere), similar to the way bodies immersed in water are magnified. In a later monograph devoted exclusively to this topic, *Fī Ru'yat al-kawākib* (On seeing the stars), he distanced himself somewhat from Ptolemy's explanation. In his masterful compendium *al-Manāẓir* (Optics) Ibn al-Haytham correctly identified the problem as one belonging to the psychology of perception, though he did allow that thick vapors could sometimes be a secondary factor.

Ibn al-Haytham's writings are distinguished by a clarity of exposition and originality of approach. He contributed to the technical literature on astronomy, but at the same time he strove to make astronomical knowledge accessible to a wider public. *On the Configuration* employs minimal mathematics. It could thus be understood by philosophers, the audience most troubled by the discrepancies between mathematics and physics; this is probably one reason for its great success. Ibn al-Haytham's commentary to the *Almagest*, unlike other commentaries that had been written before, aimed to clarify obscure points for the beginner. His monograph *Fī Kayfiyyat al-arṣād* (On the method of [astronomical] observations) offers a historical explanation, unique in medieval literature, of how astronomical theory was built on observation.

Ibn al-Haytham also authored several monographs on isolated problems, such as the determination of the meridian and of the *qibla* (*i. e.*, the direction of Mecca), sundials, and the visible appearance of the lunar surface.

Y. Tzvi Langermann

Alternate names

Alhazen
al-Haytham

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Ibn ˁIrāq: Abū Naṣr Manṣūr ibn ˁAlī ibn ˁIrāq

Born **Gīlān, (Iran), *circa* 950**
Died **Ghazna, (Afghanistan), *circa* 1036**

Ibn ˁIrāq was an astronomer who also made important contributions to trigonometry. His name and contemporary references to him as "prince" (*al-amīr*) suggest that he was a member of the Banū ˁIrāq dynasty, which ruled Khwārizm until the Ma'mūnī dynasty conquered it in 995.

Ibn ˁIrāq was a pupil of the famous scientist **Abū al-Wafā' al-Būzjānī,** and he, in turn, had a pupil who became one of medieval Islam's most famous scientists, **Abū al-Rayḥān al-Bīrūnī**. Among Abū Naṣr's works are a number of treatises answering questions posed by Bīrūnī.

At some point in the early 11th century—1016 has been suggested—both Ibn ˁIrāq and Bīrūnī joined the court of Maḥmūd of Ghazna, Afghanistan, where Ibn ˁIrāq passed the rest of his life.

Ibn ˁIrāq was a capable astronomer, and Bīrūnī praised his method for finding the solar apogee as one that was as far beyond the methods of the modern astronomers as theirs were beyond those of the ancients. However, his chief astronomical work, the *Royal Almagest* (*al-Majisṭī al-shāhī*), is lost, with only fragments surviving. The same is true of his *Book of Azimuths*, on methods for finding the direction of Mecca (the *qibla*). Of Ibn ˁIrāq's surviving astronomical writings, a number of them deal with astrolabes, while others correct errors or comment on astronomical writings of such predecessors as **Ḥabash al-Ḥāsib** and **Abū Jaˁfar al-Khāzin**.

In another fragment of a lost writing, Abū Naṣr takes issue with a colleague who suggested that the planetary orbits might be ellipses, rather than circles, with a very slight difference between their major and minor axes. He also discusses the possibility that the motions of the planets in their orbits might be, not only apparently but in reality, nonuniform. Abū Naṣr comes down firmly for the prevailing ancient and medieval view, however, that all heavenly bodies move with uniform motion on circles.

Among Ibn ʿIrāq's most famous contributions to mathematical astronomy are his discoveries of both the Law of Sines (for plane and spherical triangles) and the polar triangle (of a spherical triangle). Indeed, it appears he got into a controversy with his teacher, Abū al-Wafāʾ, over priority in the discovery of the former. (It is quite possible, of course, that each discovered it independently of the other since many important mathematical discoveries have been made simultaneously by more than one person.) In any case, it is certain that Abū Naṣr brought the Sine Law into the mathematical limelight with his repeated use of the theorem and the several proofs he gave of it.

This interest in spherical trigonometry is very much in line with Abū Naṣr's preparing a reliable Arabic edition of the *Spherica* of **Menelaus**, the first treatise to focus on the importance of the spherical triangle.

It is interesting that the title of one of Ibn ʿIrāq's treatises (*On the reason for the followers of the Sindhind halving the equation*) shows that even in the late 10th or early 11th century astronomers of the caliber of Abū Naṣr were discussing seriously the contents of the then very ancient material of the Indian tradition in the *Sindhind*.

J. Len Berggren

Alternate name

Irāq

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Ibn Isḥāq: Abū al-ʿAbbās ibn Isḥāq al-Tamīmī al-Tūnisī

Flourished **Tunis (Tunisia) and Marrakech (Morroco), *circa* 1193–1222**

Ibn Isḥāq was a Tunisian astronomer who left an unfinished *zīj* (an astronomical handbook with tables) with a few canons and instructions for their use; this marked the first of a family of Maghribī astronomical works of this kind. The *zīj* was heavily influenced by the Toledan astronomer **Ibn al-Zarqālī**, and therefore characteristically contained sidereal mean motion tables, a model for the trepidation of the equinoxes, a solar model with variable eccentricity, and Zarqālī's correction of the Ptolemaic lunar model as well as some of his parameters. Before Ibn Isḥāq, we only know for the Maghrib that at the beginning of the 11th century the famous astrologer Ibn Abī al-Rijāl al-Qayrawānī composed a *zīj*, which, unfortunately, has been lost.

Until recently the only known references to Ibn Isḥāq were from:

1. the famous historian Ibn Khaldūn (1332–1382), who says, in his *Muqaddima*, that he was an astronomer at the beginning of the 13th century who composed his *zīj* using (his own) observations as well as the information he obtained through correspondence with a Sicilian Jew who was competent in astronomy and a good teacher; and
2. **Ibn al-Bannāʾ al-Marrākushī** (1256–1321) who states in his *Minhāj al-ṭālib fī taʿdīl al-kawākib* that Ibn Isḥāq made observations in Marrakech, that his book was written on cards or independent sheets (*baṭāʾiq*), and (in one manuscript) that some of his tables were calculated for the year 1222.

Much more information on Ibn Isḥāq has been gathered due to the discovery, by David A. King, of Hyderabad, Andhra Pradesh State Library MS 298, copied in Homs (Syria) in 1317, which contains the most important collection of materials derived from Ibn Isḥāq as well as from other (mainly Andalusian) sources. This compilation was made by an anonymous Tunisian astronomer who flourished *circa* 1267–1282. It contains a strange table with the names and dates of astronomers who established, purportedly by observation, the position of the solar apogee and the obliquity of the ecliptic. One of them is Ghiyām ibn Rujjār in 1178, who can be identified as William II (who reigned in Sicily between 1166 and 1189), the son of William I and grandson of Roger II. William II is undoubtedly the patron of the unnamed Jewish astronomer mentioned by Ibn Khaldūn. Another of the "observers" is Ibn Isḥāq himself, and the date given is 1193. The date (1222) mentioned in one manuscript of Ibn al-Bannāʾs *Minhāj* is confirmed by Ibn Isḥāq's table of the solar equation that reaches a maximum value of 1° 49′ 7″. This amount can be calculated (using Ibn Isḥāq's own tables based on a Zarqālian solar model with variable eccentricity) precisely for the year 1222.

Ibn Isḥāq seems to have left only one set of numerical tables (nos. 6–58 of the Hyderabad manuscript) for the computation of planetary longitudes, eclipses, equation of time, parallax and, probably, solar and lunar velocity. These tables were not accompanied by an elaborate collection of canons, although they contained instructions of some kind for the use of a few tables. His *zīj*, therefore, was unfinished and not ready to be used. This is why the anonymous compiler of the Hyderabad manuscript tried to finish this work and to "edit" Ibn Isḥāq's *zīj* by adding both canons and numerical tables. The whole constitutes an impressive collection of materials in which the predominant influence is clearly Andalusian, but we do not know yet to what extent Ibn Isḥāq's contributions are original. His solar tables are clearly Zarqālian in origin; the maximum equations of the center for the planets are Ptolemaic for Mars, Mercury, and the Moon; and the case of Venus (1° 51′) may derive from a new computation of the solar eccentricity using Zarqālī's solar model with variable eccentricity. On the other hand, the values for Saturn (5° 48′) and Jupiter (5° 41′) seem new.

This unknown Tunisian compiler was not the only "editor" of the tables of Ibn Isḥāq. Two other contemporaries prepared "editions" of the same work. One of them was Ibn al-Bannāʾ who wrote his *Minhāj* with the same purpose. The other was **Muḥammad ibn al-Raqqām** of Tunis and Granada, who is the author of three different versions of Ibn Isḥāq's *zīj*.

The *zīj*es derived from Ibn Isḥāq were used in the Maghrib until the 19th century, for they allowed the computation of sidereal longitudes that were used by astrologers. We have a limited amount of information about the observations made in the Maghrib in the 13th and 14th centuries, which established that precession exceeded the amounts fixed in Andalusian trepidation tables and that the obliquity of the ecliptic had fallen below the limits of Zarqālī's model and tables. This explains the introduction of eastern *zīj*es in the Maghrib from the 14th century onward: Those of **Ibn Abī al-Shukr al-Maghribī** and **Ibn al-Shāṭir** were known in the late 14th century, while the *Zīj-i jadīd* of **Ulugh Beg** did not reach the Maghrib until the end of the 17th century. In them, mean motions were tropical and constant precession was used instead of trepidation, and there were no tables to compute the obliquity of the ecliptic. They were used by astronomers while astrologers stuck to Ibn Isḥāq's tradition.

Julio Samsó

Alternate name

Isḥāq

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Ibn al-Kammād: Abū Jaʿfar Aḥmad ibn Yūsuf ibn al-Kammād

Flourished **al-Andalus, (Spain), beginning of the 12th century**

Ibn al-Kammād was a well-known astronomer from al-Andalus who influenced a number of later astronomers' writing in the Arabic, Hebrew, and Latin astronomical traditions. There is, however, little information about his life. He was probably born in Seville although he spent his working life in Cordova. Ibn al-Kammād was a direct or indirect disciple of **Zarqālī** (11th century). Later astronomers from al-Andalus, North Africa, and the Iberian Peninsula refer to him, and references to him occur in Arabic, Latin, and Hebrew sources. He seems to have also been known in eastern Islamic countries. The reference to a horoscope cast by Ibn al-Kammād in Cordova in 1116–1117 that appears in the extant version of **Ibn Isḥāq al-Tūnisī**'s *zīj* suggests that he flourished at the beginning of the 12th century. Some modern sources, from the 19th century onward, suggest that he died in 1195; however, in light of the aforementioned horoscope, this date should be reconsidered.

Ibn al-Kammād wrote three *zīj*es (astronomical handbooks with tables): *al-Kawr ʿalā al-dawr*, *al-Amad ʿalā al-abad*, and *al-Muqtabas*, which is a compilation of the two previous *zīj*es. None survives in a complete version of the original Arabic. What has survived is the Latin translation of *al-Muqtabas* made by John of Dumpno in 1260 in Palermo (Biblioteca Nacional de Madrid, MS 10023). The same manuscript contains several chapters that do not belong to *al-Muqtabas*; some of them are probably related to *al-Kawr*. They too were translated by John of Dumpno in 1262 in Palermo. Furthermore, there are also some tables that do not belong to *al-Muqtabas* in the last folios of the manuscript, two of which are related to the city of Sale (Morocco). Some fragments of *al-Kawr* and Chapter 28 of *al-Muqtabas* are preserved in Arabic (Escorial MS 939 and Alger MS 1454).

A Castilian translation of a chapter on trepidation by Ibn al-Kammād is preserved in the Cathedral of Segovia Library (MS 115). This may belong to one of his *zīj*es, though there are no instructions on the use of the tables as would be expected in the canons of a *zīj*. The manuscript also contains some Alfonsine texts. In the chapter entitled *Libro sobre çircunferencia de moto sacado por tiempo seculo*, which seems to be a translation of *al-Kawr ʿalā al-dawr* (The periodic rotations) and/or *al-Amadʿalā al-abad* (For the span of eternity), Ibn al-Kammād makes an error with respect to Zarqālī's trepidation model. He assumes that the motion of the pole of the ecliptic around its polar epicycle is equal to the motion of the Head of Aries around its equatorial epicycle. An explanation showing the same error and attributed to "some astronomers" is found in **Naṣīr al-Dīn al-Ṭūsī**'s *Tadhkira*. Another Arabic text by Ibn al-Kammād is preserved in the Iraq Museum of Baghdad (MS 296 [782]), though it has not been studied to date.

Ibn al-Kammād also wrote an astrological treatise, the *Kitāb Mafātīḥ al-asrār*, of which only Chapters 10–15 are extant. These chapters (*kalām fī al-naymūdār li-taṣḥīḥ ṭawāliʿ al-mawālid*), on astrological obstetrics, explain how to use astronomical measurements to determine the duration of a pregnancy. They are related to *al-Kawr* and to some of the tables accompanying, but not belonging to, *al-Muqtabas*.

Ibn al-Kammād was strongly criticized by **Ibn al-Hāʾim al-Ishbīlī** in the latter's *al-Zīj al-kāmil* (*circa* 1205); Ibn al-Hāʾim notes as many as 25 errors in Ibn al-Kammād's work, especially in *al-Kawr ʿalā al-dawr* and *al-Amad ʿalā al-abad*. These have mainly to do with solar and lunar motions, trepidation models, trigonometry, timekeeping, and astrology. However, Ibn al-Kammād's influence is to be seen in a number of later astronomers writing in Arabic, Hebrew, and Latin, such as **Abū al-Ḥasan al-Marrākushī** (in the 13th century), Juan Gil, al-Ḥadib, Joseph ibn Waqār, and, in particular, Jacob Corsuno, the author of the *Tables of Barcelona* dedicated to King Peter the Ceremonious in the 14th century.

Mercè Comes

Alternate name

al-Kammād

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Ibn Labbān, Kūshyār: Kiyā Abū al-Ḥasan Kūshyār ibn Labbān Bāshahrī al-Jīlī (Gīlānī)

Born **Gīlān, (Iran)**
Flourished **second half 10th/early 11th century**

Kūshyār ibn Labbān was an eminent Iranian astronomer known for his work on astronomical handbooks (*zīj*es) in addition to his work in mathematics and astrology. All of his scientific legacy is in Arabic. The title Kiyā (literally, "king/ruler") was used in his time for the names of authorities and scholars. His given name, "Kūshyār," is the arabicized form of the ancient Persian name Gūshyār, which literally means "a gift of Gūsh" or "aided by Gūsh," Gūsh being the name of an angel in the Zoroastrianism religion that had prevailed in Iran before Islam. There remains very little information about his life. He was from Gīlān province and later moved to Rayy (near present-day Tehran) where he met **Abū Rayḥān al-Bīrūnī**. He then moved to Jurjān in Ṭabaristān, a province adjacent to Gīlān, where he worked as the astronomer at the court of the Ziyārid dynasty. We know from al-Bīrūnī that Kūshyār learned of the Sine Theorem from the work of his contemporary **Abū Maḥmūd al-Khujandī** and referred to it as *al-shakl al-mughnī* (literally, "The theorem that makes the [Menelaus Theorem] expendable").

Kūshyār's major work in astronomy, the *jāmiʿ Zīj* (Universal/Comprehensive astronomical handbook with tables) was influenced by **Ptolemy**'s *Almagest* and **al-Battānī**'s *zīj*. It contains many tables concerning trigonometry, astronomical functions, star catalogs, and geographical coordinates of cities. It comprises four books (*maqāla*'s): calculations, tables cosmology, (containing a chapter on "Distances and sizes" of the celestial bodies and the Earth), and proofs. **Al-Nasawī** (10th/11th centuries), who was supposed to have been Kūshyār's disciple, wrote a commentary on Book I. Book I was translated into Persian about one century after Kūshyār. The entire *Zīj* was transliterated into Hebrew characters, which may be pieced together from fragments dispersed in several Hebrew manuscripts.

Kūshyār's *Bāligh Zīj* (The extensive astronomical handbook with tables), to which he refers in the introduction to his astrological treatise, is not extant. Only a short chapter entitled "On the use of planets' cycles according to the Indian method" remains in a Bombay manuscript.

Kūshyār's *Risāla fī al-asṭurlāb* (Treatise on the astrolabe) is extant in several manuscripts. It consists of four sections: necessary elements, other materials rarely needed, checking the astrolabe, its circles and lines, and making astrolabes. An edition of the Arabic text, prepared by Taro Mimura in Kyoto, has not yet been published, but an edition of an old Persian translation, prepared by M. Bagheri, was published in 2004.

Al-mudkhal fī ṣināʿat aḥkām al-nujūm (Introduction to astrology), also named *Mujmal al-uṣūl fī aḥkām al-nujūm* (Compendium of principles in astrology), is Kūshyār's famous treatise on astrology, composed around 990. Extant in numerous manuscripts, it comprises four books: an introduction and principles, prediction of world affairs, judgments on nativities and their year transfers, and choices (of suitable times). There are old Persian and Chinese translations of this work, the latter having been printed three times. There is also a Turkish commentary extant in Istanbul (Hamidiye MS 835).

As for his mathematical work, Kūshyār is noted for his *Uṣūl ḥisāb al-hind* (Principles of Hindu reckoning), which is extant and deals with algorithms for arithmetic operations in decimal and sexagesimal bases. It was translated into Hebrew by Shalom ben Joseph ʿAnābī in the 15th century (Oxford, Bodleian library, MS Oppenheim 211); in modern times it has been translated into English, French, Persian, and Russian.

Mohammad Bagheri

Alternate name

Labbān, Kūshyār

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Ibn al-Majdī: Shihāb al-Dīn Abū al-ˁAbbās Aḥmad ibn Rajab ibn Ṭaybughā al-Majdī al-Shāfiˁī

Born **Cairo, (Egypt), August 1366**
Died **Cairo, (Egypt), 27/28 January 1447**

Ibn al-Majdī was one of the major Egyptian astronomers during the first half of the 15th century. He occupied the positions of *muwaqqit* (timekeeper) at al-Azhar Mosque and of “head of the teachers” at the Jānibakiyya *madrasa* (privately endowed religious college).

Ibn al-Majdī received a traditional religious education in the fields of Quranic studies, the prophetic traditions (*ḥadīth*), jurisprudence (*fiqh*), and Arabic grammar and philology. He also became an expert in arithmetic, geometry, the algebra of inheritance, theoretical astronomy (*hay’a*), and applied astronomy (*mīqāt*, literally, the science of timekeeping). He learned the latter discipline under Jamāl al-Dīn al-Māridīnī, who had been a student of the celebrated astronomer of Damascus, **Ibn al-Shāṭir**. Later, Ibn al-Majdī himself became a highly regarded teacher in most of the above-mentioned traditional disciplines as well as in the mathematical sciences. Virtually all of his younger contemporaries and immediate successors who were active in astronomy in Cairo were his pupils at one time or another. A prolific and competent writer, Ibn al-Majdī played an important role as a didactic author; his writings were still read and commented upon in Egypt in the late 19th century.

Ibn al-Majdī’s numerous astronomical treatises deal with a wide range of topics. Several of them are devoted to the compilation of annual ephemerides but have yet to be carefully studied, notably his important treatise *Jāmiˁ al-mufīd fī bayān uṣūl al-taqwīm wa-’l-mawālīd* (which also deals with arithmetic, chronology, and astrology) and his *Ghunyat al-fahīm wa-’l-ṭarīq ilā ḥall al-taqwīm*. However, his important set of auxiliary tables for facilitating the calculation of planetary positions, entitled *al-Durr al-yatīm fī tashīl ṣināˁat al-taqwīm*, has been investigated by E. S. Kennedy and D. King. These tables contain numerical entries for the Sun, Moon, and planets and make a clever use of periodic relations very similar to those that are at the core of Babylonian astronomy combined with an intelligent application of the methods and parameters of Ptolemaic *zīj*es (astronomical handbooks). An anonymous set of such auxiliary tables based on the same principle is known from 11th-century Iran, so we are witnessing an older tradition that reappeared in Cairo, *circa* 1400. Ibn al-Majdī’s auxiliary tables, supplemented by his contemporaries and successors, were extremely popular in Egypt up to the 19th century and inspired other, more extensive sets of tables based on the same methods and on the newer parameters of the *zīj* of **Ulugh Beg**.

Ibn al-Majdī's activities dealt intensively with astronomical instruments. He composed numerous works, often didactical in character, dealing with the astrolabe, the theory of stereographic projection, the use of the standard astrolabic and sine quadrants as well as several unusual varieties of quadrants (most of which had been invented by his 14th-century predecessors), and works on sundial theory. Among his writings we also find treatises on the determination of the lunar crescent visibility, a topic of prime importance to Muslim religious practice since the Islamic calendar is lunar. Ibn al-Majdī also dealt with the applied problems of finding the *qibla* (the holy direction toward Mecca) and the orientation of roof ventilators.

Ibn al-Majdī's contributions to arithmetic and algebra deserve further investigation. His treatise on sexagesimal arithmetic, a topic of fundamental importance for astronomers, was praised by his former pupil **Sibṭ al-Māridīnī** as being the only satisfactory treatment of the subject known to him.

As a rule, astronomers during the Mamluk period in Egypt and Syria (1250–1517) did not engage in astrology because of their associations with religious institutions—either as *muwaqqit*s in mosques or as teachers in *madrasa*s or Sufi convents. Ibn al-Majdī was something of an exception: A noted religious scholar, he nevertheless treated the topic of mathematical astrology in his *al-Jāmiʿ al-mufīd* and even cast a horoscope for a Mamluk amīr.

François Charette

Alternate name

al-Majdī

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Ibn Muʿādh: Abū ʿAbd Allāh Muḥammad ibn Muʿādh al-Jayyānī

Died **probably (Spain), after 1079**

Ibn Muʿādh al-Jayyānī was the author of several astronomical works, and yet very little is known about him. Recent scholarship suggests that he was born in the early 11th century. The only secure date we have for him is 1079, the year of a solar eclipse he describes from first-hand observation. "Jayyānī" means from Jaen, the capital of the Andalusian province of the same name where he served as a *qāḍī* (judge) for much of his life. In fact, he belonged to a family of judges and jurists from that province.

Among Ibn Muʿādh's astronomical works was the *Tabulae Jahen*, a set of astronomical tables probably translated into Latin by **Gerard of Cremona** with the title *Liber tabularum Iahen cum regulis suis*. A printed edition of the canons, lacking the tables, appeared in 1549 at Nüremberg as *Scriptum antiquum saraceni cuiusdam de diversarum gentium Eris, annis ac mensibus et de reliquis Astronomiae principiis*. These tables were based on the tables of **Khwārizmī**, and were adapted to the geographical coordinates of Jaen for the epoch of midnight, 16 July 622 (the date of the *hijra)*. But there are some modifications introduced by Ibn Muʿādh, such as the value of the geographical longitude of the city, which are in accordance with the corrected values found in Andalusian astronomers from the 10th century. In some points he seems to be independent of his sources, as is the case in Chapter 19, devoted to the visibility of the new Moon, and also in the trigonometric section. This work included a table of stars that improved the one in Khwārizmī and was also independent of the Toledan tradition. In Chapter 18 we find the first exact method used in Andalusia to determine the azimuth of the *qibla*, the so-called *method of the zījes*, probably taken from a work by **Bīrūnī**. In short, there is considerable new material as well as a personal vision; in addition there is a possible influence from eastern astronomers such as Bīrūnī, who until recently was thought not to have been known in Andalusia.

Although we do not have evidence of any astronomical observation made by Ibn Muʿādh, there is a treatise on the solar eclipse already mentioned, which occurred on 1 July 1079. The text of this treatise, "On the Total Solar Eclipse," was translated into Hebrew by Samuel ben Jehuda (flourished: *circa* 1335). Another treatise by him, entitled "On the Dawn," was also translated into Hebrew. The Arabic texts of these two works are not known to be extant. A Latin translation of the latter work was made by Gerard of Cremona as the *Liber de crepusculis*. It deals with the phenomena of morning and evening twilight, and in it Ibn Muʿādh gives an estimation of the angle of depression of the Sun at the beginning of the morning twilight and at the end of the evening twilight, obtaining the value of 18°. On the basis of this and three other basic parameters (the mean distance between Earth and Sun [1,110 in terrestrial radii], the relative size of Sun and Earth [5.5:1 in terrestrial radii], and the circumference of the Earth [24,000 miles]), and through the use of simple trigonometric functions, Ibn Muʿādh calculates the height of the atmosphere to be around 52 miles. The work found a wide interest in the Latin Middle Ages and in the Renaissance, and this figure, 52 miles, remained canonical in the Latin West until the end of the 16th century, when the issue of atmospheric refraction was raised to prominence by **Tycho Brahe**. Consequently, this figure of 52 miles was drastically reduced by **Johannes Kepler** and succeeding astronomers.

An astrological work by Ibn Muʿādh is *Maṭraḥ shuʿāʿāt al-kawākib* (Projection of the rays of the stars) is preserved in an Arabic copy in the Biblioteca Medicea Laurenziana Orientale 152. Although as yet not properly studied, it seems to be the source of later works on the subject such as the *Libro del Ataçyr* composed under the patronage of **Alfonso X** the Wise in Toledo in the 13th century and included among the *Libros del Saber de Astronomía*.

Several mathematical works by Ibn Muʿādh are also extant in Arabic. His treatise *Kitāb Majhūlāt qisī al-kura* (Determination of the magnitudes of the arcs on the surface of a sphere), which is also cited in his *Tabulae Jahen*, is a work on spherical trigonometry, probably the most ancient treatise on this topic in the medieval west. It is also a text in which this discipline is entirely independent from astronomy, and in which the author shows that he was aware of the main novelties introduced by Eastern Islamic mathematicians at the end of the previous century. Ibn Muʿādh probably had access to Eastern literature on spherical trigonometry, but he was also capable of dealing with this subject in an independent way.

The *Maqāla fī sharḥ al-nisba* (On ratio) is a defense of Euclid. It falls into a tradition of geometric research documented in the works of earlier Andalusian mathematicians such as Mu'taman ibn Hūd and Ibn Sayyid. Ibn Muʿādh says in his preface that this treatise is intended "to explain what may not be clear in the fifth book of Euclid's writing." There was a general dissatisfaction among Arabic mathematicians with Euclid V, definition 5. As a consequence of the abstract form in which the Euclidean doctrine of proportions was presented, the Arabs, from the ninth century on, tried either to obtain equivalent results more in accord with their own views, or to find a relation between their views and the unsatisfying theory. The most successful among them was Ibn Muʿādh, who showed an understanding comparable with that of Isaac Barrow, who is customarily regarded as the first to have really understood Euclid's Book V.

Emilia Calvo

Alternate name

Muʿādh

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Ibn al-Raqqām: Abū ʿAbd Allāh Muḥammad ibn Ibrāhīm ibn ʿAlī ibn Aḥmad ibn Yūsuf al-Mursī al-Andalusī al-Tūnisī al-Awsī ibn al-Raqqām

Born **probably Murcia, (Spain), *circa* 1250**
Died **Granada, (Spain), 27 May 1315**

Ibn al-Raqqām was a prolific author who wrote on numerous branches of learning. According to the Andalusian historian Ibn al-Khaṭīb (1313–1374), he was a versatile master (*shaykh*), unique in his time for his skills in arithmetic, geometry, medicine, astronomy, and other disciplines. Though probably a native of the region of Murcia, it is clear that he lived for a time in North Africa. One of his preserved works (*al-Zīj al-qawīm*) indicates that Ibn al-Raqqām lived in Tunis, since a number of tables are calculated for the coordinates of this city. That he also lived in Bijāya (Bejaïa, in Algeria) is confirmed by the existence of many astronomical tables computed for the latitude of this city in another of his extant works (*al-Zīj al-shāmil*). At the invitation of the second king of the Naṣrid dynasty, Muḥammad II (1273–1302), Ibn al-Raqqām left Bijāya for Granada, where he lived until his death. Ibn al-Raqqām taught medicine and jurisprudence in addition to other subjects. He had two known students: Abū Zakariyyā' ibn Hudhayl (died: 1352), who studied mathematics, geometry, algebra, and astronomy, and Naṣr, another ruler of the Naṣrid dynasty (reigned: 1309–1314), who studied the composition of almanacs and the construction of astronomical instruments.

Ibn al-Raqqām wrote a number of astronomical works, of which three are extant. Two of these, are *zīj*es (astronomical handbooks with tables), *al-Zīj al-shāmil fī tahdhīb al-kāmil*, and *al-Zīj al-qawīm fī funūn al-taʿdīl wa-'l-taqwīm*. *Al-Zīj al-shāmil* was composed in 1280/1281 in Tunis. According to the introduction, his aim was to make appropriate improvements to **Ibn al-Hā'im**'s *al-Zīj al-kāmil.* These included condensing the explanations of this book, adding tables missing in the original, and revising parameters in order to reach a better agreement between computation and observation. One of the modifications made by Ibn al-Raqqām in the explanations, or *canons*, consisted of copying the words of Ibn al-Hā'im without his careful geometrical demonstrations. The additional tables added by Ibn al-Raqqām are, in general, those of **Ibn Isḥāq al-Tūnisī**. Ibn al-Raqqām's *zīj* thus represents one of three known editions of Ibn Isḥāq's work produced at approximately the same time, the other two being the *zīj* of **Ibn al-Bannā'** and an anonymous recension (written *circa* 1266–1281) preserved in Hyderabad. *Al-Zīj al-qawīm* seems to be a simplified version of *al-Zīj al-shāmil*, with a simplified set of canons and the adaptation of some tables to the geographical coordinates of Granada. On the whole, both *zīj*es are similar in format and share several numerical tables; however, there are differences since some similar tables in each *zīj* have been formulated for a specific location. For example, the tables in *al-Zīj al-shāmil* for computing daylight lengths and unequal hours are calculated for a stated latitude of 36°, which applies to Bijāya, while in *al-Zīj al-qawīm* they are for 36° 37′, the latitude of Tunis. Moreover, the latter *zīj* has a table for lunar visibility calculated for the latitude of Granada, given as 37° 10′, a different figure from the usual one for Granada in medieval times.

This indicates that Ibn al-Raqqām reworked *al-Zīj al-qawīm* after his arrival in Granada and that he must have made a very precise determination of the latitude of this city, for the value he uses is exactly the modern one.

The other preserved astronomical work of Ibn al-Raqqām, his *Risāla fī ˁilm al-ẓilāl*, represents the only complete Arabic treatise on gnomonics of Andalusian origin. The work, organized into 44 chapters, is devoted to the construction of several kinds of sundials and discusses the mathematical and astronomical principles relevant to gnomonics, such as the determination of hour lines or the curves of the lines for the midday (*ẓuhr*) and afternoon (*ˁaṣr*) prayers. Ibn al-Raqqām's presentation is well organized, graphic, and descriptive; the work also demonstrates his ability to use the analemma, a graphical technique not previously known in Andalusian gnomonics.

Ibn al-Khaṭīb refers to another astronomical work by Ibn al-Raqqām, which may have been a revision of *al-Manāj fī ru'yāt al-ahilla* (on lunar crescent visibility) of Ibn al-Bannā'. Nonastronomical works by Ibn al-Raqqām mentioned by Ibn al-Khaṭīb include a work written in the style of **Ibn Sīnā**'s encyclopedic *Kitāb al-Shifā'*, the *Abkār al-afkār fī al-uṣūl* (on jurisprudence), a summary of the *Kitāb al-Ḥayawān wa-'l-khawāṣṣ* (probably a treatise on medical cures using parts of the body of animals).

Josep Casulleras

Alternate name

al-Raqqām

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Ibn Rushd: Abū al-Walīd Muḥammad ibn Aḥmad ibn Muḥammad ibn Rushd al-Ḥafīd

Born **Cordova, (Spain), 1126**
Died **Marrakech, (Morocco), 10 December 1198**

Ibn Rushd, one of the best-known Islamic philosophers, challenged **Ptolemy**'s astronomical system on philosophical grounds and made interesting theoretical contributions to the Andalusian criticisms of the Greek astronomer. Along with **Ibn Bājja**, **Ibn Ṭufayl**, and **Biṭrūjī**, he wished to formulate a model for the cosmos according to Aristotelian principles – *i. e.*, uniform and circular motions centered on the Earth – in which there was no need for eccentrics and epicycles. He was also an active and a first-rate scholar in many other disciplines, including Islamic religion and law, medicine, and the various aspects of Hellenistic philosophy.

Ibn Rushd was born into an important family of religious scholars, but in addition to religious sciences, he also studied medicine and astronomy. We know little of his formative period; he probably studied in Cordova and Seville, learning medicine from a physician named Ibn Jurrayūl. In Seville he met Abū Jaˁfar ibn Hārūn al-Tarjālī, a court physician who also had a profound knowledge of philosophy and mathematical sciences; Ibn Rushd became his pupil in these disciplines. In his *Summary of the Almagest,* Ibn Rushd himself mentions a master in astronomy named Abū Isḥāq ibn Wādiˁ, who is otherwise unknown. We know that in 1153 Ibn Rushd was in the service of the Almohads, a North African dynasty that ruled Muslim Spain (al-Andalus) and North Africa for many years. In 1153, according to his commentaries to **Aristotle**'s *De Caelo*, he observed several stars in Marrakech. In the *Summary of the Almagest*, Ibn Rushd goes on to say that he calculated the positions of Venus and Mercury, under the supervision of Abū Isḥāq ibn Wādiˁ, in order to check a conjunction of these planets with the Sun allegedly observed by the nephew of the Andalusian astronomer **Ibn Muˁādh**. These autobiographical data, together with his treatise on the *Almagest*, bear witness to a thorough knowledge of the fundamentals of astronomy, though he did not pursue these studies in his later years.

The personal and intellectual sides of Ibn Rushd's life are inseparable, and both were decisively determined by the fortunes of the Almohad dynasty. These rulers had attained power advocating a new interpretation of Islam that was based on the thought of Ibn Tūmārt. The new ideology had a rationalistic side applied to religion that favored the growth of rational speculation and, therefore, of philosophy and science. Furthermore, between 1163 and 1184 the dynasty was ruled by Caliph Abū Yaˁqūb Yūsuf, a man of learning interested in philosophy, medicine, and astronomy, to whom Ibn Rushd was introduced, perhaps about 1169, by the philosopher and court physician Ibn Ṭufayl. According to the chronicles, Caliph talked with the two philosophers about complex issues of faith and philosophy such as the eternity of the world. Ibn Ṭufayl later told Ibn Rushd that the caliph had complained about the obscurity of Aristotle's texts and wished to find someone able to explain them and make them more generally accessible. Whether or not this story is true, Ibn Rushd spent the rest of his life involved in this task, and became the leading commentator on Aristotle, while working for the court administration as physician, judge, and theologian. He held the posts of judge of Seville (1169) and Cordova (1171) and later became chief judge of Cordova (1182); also in 1182, he succeeded Ibn Ṭufayl as the caliph's doctor. By this time, Ibn Rushd had been promoted to the highest ranks of the Almohad hierarchy because of his intellectual activity, mainly in the fields of medicine and law. During his last years (1195–1197), he fell into disgrace and was prosecuted together with other intellectuals because Caliph al-Manṣūr, challenged by the Christians, sought to gain the favor of a party of influential religious scholars who were hostile to the growth of philosophical speculation. He was exiled to Lucena (south of Cordova), but shortly before his death Ibn Rushd was rehabilitated and returned to the capital of the kingdom.

Ibn Rushd wrote his most important work on astronomy, the *Mukhtaṣar al-Majisṭī* (Summary of the *Almagest*), at the beginning of his career, sometime between 1159 and 1162. Perhaps under the influence of Ibn Bājja, it was written in a period characterized by his search for those aspects of science necessary for human perfection. For this reason, his astronomical work shares many features with his medical writings, especially the *Kulliyyāt fī al-ṭibb* (Generalities on medicine), where (also under the influence of Ibn Bājja) Ibn Rushd discusses the role of philosophy for dealing with scientific materials. However, being less expert than in medicine, his *Summary of the Almagest* is more an attempt to understand the scope of theoretical astronomy in his time rather than an attempt at an authoritative work such as represented by the *Kulliyyāt*. Ibn Rushd asks to what extent astronomy can be considered a true science and deals not only with mathematical astronomy but also with the physical representation of the cosmos. He discusses Ptolemy, comparing and contrasting his work to some of the most important Arabic and Andalusian mathematical astronomers who criticized parts of his system but respected its fundamentals. Ibn Rushd's main sources are the *Iṣlāḥ al-Majisṭī* (Corrections to the *Almagest*) of the Andalusian **Jābir ibn Aflaḥ**, the *Kitāb Fī hay'at al-ˁālam* (Book on the configuration of the World) and *al-Shukūk ˁalā Baṭlamyūs* of the Egyptian **Ibn al-Haytham**, and the treatises by the Andalusian **Zarqālī** on the motion of the fixed stars and on the Sun. Though he seems convinced that astronomy needs to be thoroughly redefined, in the meantime he is obliged to rely upon the questions on which all the astronomers agree. His short commentaries (*jawāmiˁ*) to Aristotle's works (generally written during the same period of his life) reflect the doubtful opinions expressed in the *Mukhtaṣar al-Majisṭī*. Underlying his short commentaries to the *De Caelo* and *Metaphysics* is the paradigm of contemporary astronomy even though it contradicts Aristotle. However, Ibn Rushd disagrees with Ptolemy and Islamic astronomers on many points such as the existence of a ninth sphere. To deal with these contradictions, he uses ambiguous explanations such as the metaphor of the "universal animal" (*ḥayawān kullī*) found in Ptolemy's *Planetary Hypothesis*, also echoed in Ibn Ṭufayl's *Risālat Ḥayy ibn Yaqẓān*, which he uses to pose the problem of the existence of several motions in the planets in different directions.

Ibn Rushd's opinions evolved during the second period of his work, which was characterized by a strict reading of Aristotle, freeing it from the opinions that both Hellenistic and Islamic philosophy had added to it. For this reason, in his long commentaries (*tafāsīr*) to *De Caelo* and the *Metaphysics* in particular, he openly rejects the existence of eccentrics and epicycles insofar as they contradict the necessity of circular and uniform motions around the Earth for the planets. The main problem is that Ibn Rushd is not aware of the astronomical theories formulated by **Eudoxus** and **Callippus** that underlie the Aristotelian cosmos and so has great difficulty in understanding Aristotle's texts on this point. Having no time and insufficient knowledge (as he himself confesses) to formulate a new proposal that allows the coexistence in the same model of the apparent planetary motions alongside Aristotelian tenets, he only suggests that planets have a spiral movement that accounts for both daily motion and motion in longitude. This intuitive idea based on the observation of the Sun (also shared by Biṭrūjī) has some precedents in **Plato** and **Theon of Alexandria**, but in Ibn Rushd seems to have sprung from a misreading of Aristotle.

Miquel Forcada

Alternate names

Averroes
Rushd

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Ibn al-Ṣaffār: Abū al-Qāsim Aḥmad ibn ʿAbd Allāh ibn ʿUmar al-Ghāfiqī ibn al-Ṣaffār al-Andalusī

Born **Cordova, al-Andalus, (Spain)**
Died **Denia, al-Andalus, (Spain), 1035**

Ibn al-Ṣaffār (literally: son of a coppersmith) was a prominent astronomer at the school of **Maslama al-Majrīṭī**. Located in Cordova, this was one of the most important centers for the study of the exact sciences in Andalusia. In Cordova, Ibn al-Ṣaffār taught arithmetic, geometry, and astronomy. Among his disciples in Cordova were Ibn Bargūth, al-Wāsiṭī, Ibn Shahr, al-Qurashī, and Ibn al-ʿAṭṭār. Because of civil war, he moved to Denia, on the Eastern coastline of the Iberian Peninsula where he lived until his death. His brother, Muḥammad, who also retired in Denia, was a celebrated astronomical instrument-maker; two of his astrolabes and a plate are preserved today in the Royal Scottish Museum in Edinburgh, the Westdeutsche Bibliothek in Marburg, and the Museo Nazionale in Palermo.

Ibn al-Ṣaffār, along with his teacher Maslama al-Majrīṭī, composed works in the tradition of **Khwārizmī**'s *Sindhind*; this is especially significant since Khwārizmī's original text was lost. **Ibn al-Samḥ** and Ibn al-Ṣaffār also made two recensions. The Arabic text of the version of Maslama and Ibn al-Ṣaffār is lost, but there exist several Latin translations of it: one by **Adelard of Bath**; a revision due to Robert of Chester; and another translation attributed to the Spanish Jew, Petrus Alfonsi (flourished: late 11th/early 12th century). Ibn al-Samḥ's version has not survived either; only seven chapters from Ibn al-Ṣaffār's canons are still extant. It is difficult to establish which data were taken from Khwārizmī and which were provided by the Andalusian astronomers, in as much as materials from the Indo–Iranian, the Greco–Arabic, and the Hispanic traditions are found. Nevertheless, it seems clear that certain tables that use the meridian of Cordova or that refer to the Hispanic era are due to Maslama and his disciples.

Ibn al-Ṣaffār's most popular work was a treatise on the uses of the astrolabe, a book that was still being used in Europe during the 15th century. According to **Ṣāʿid al-Andalusī**, the treatise was written in a clear, simple, and comprehensible style. King **Alfonso X**'s astronomers often used the work. Johannes Hispalensis and Plato of Tivoli (flourished: 1134–1145) translated it into Latin. Johannes Hispalensis' translation (edited by Millás in 1955) misattributed the translation of Ibn al-Ṣaffār's treatise on the astrolabe to Maslama. This may be explained since the last chapter in the treatise is probably a fragment taken from Maslama's *zīj*, which led later scholars to attribute the entire work to the teacher Maslama rather than to the student Ibn al-Ṣaffār. The translation by Plato of Tivoli (edited by Lorch *et al.*, 1994) contains an introduction in which Plato dedicates his work to a certain Johannes David and states that this is the best Arabic treatise that he has ever read. There also exists a Hebrew version by Profeit Tibbon (**Jacob ben Makhir**) as well as one in Old Spanish and Spanish with Hebrew characters. The Arabic text was edited by J. Millás Vallicrosa (who also translated it into Catalan) in 1955.

One of the topics Ibn al-Ṣaffār analyzed was the determination of the *qibla* (direction toward Mecca); the text gives a value of 30° south of east for the *samt* of the *qibla* at Cordova, which corresponds to the azimuth of the rising Sun at the winter solstice. Ibn al-Ṣaffār also refers to **Ptolemy**'s *Geography*, which indicates that Andalusian astronomers were interested in other works apart from the *Sindhind*.

Ibn al-Ṣaffār is credited with being the author of the inscriptions on the oldest surviving Islamic sundial, made *circa* 1000, in Cordova (and preserved in the Museo Arqueológico Provincial of Cordova, Spain). On a fragment of the sundial it is possible to observe the curve for the midday (*ẓuhr*) prayer; presumably the original instrument had that of the afternoon (*ʿaṣr*) prayer. Errors on the sundial, however, could not have been made by a careful astronomer, so the instrument may not have been constructed by Ibn al-Ṣaffār himself, but perhaps was "in the manner of" Ibn al-Ṣaffār.

Mònica Rius

Alternate name

al-Ṣaffār

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Ibn Sahl: Abū Saʿd al-ʿAlā' ibn Sahl

Flourished **late 10th century**

Ibn Sahl was a geometer who worked in the late 10th century. Although he is not mentioned in the known biobibliographical sources from the medieval period, Ibn Sahl is mentioned by **Ibn al-Haytham**, whose working life spanned the late 10th and early 11th centuries. On the other hand, he commented on one of **Abū Sahl al-Kūhī**'s treatises, and Kūhī probably died before the end of the 10th century.

His two works most relevant to the history of astronomy are his *Proof that the Vault of the Heavens Is Not Completely Transparent* and his commentary on Abū Sahl al-Kūhī's treatise on the astrolabe. In the former he gives, inspired by his study of the fifth book of **Ptolemy**'s *Optics*, a proof that whatever substance one is given, such as that composing the heavenly spheres of Aristotelian cosmology, it is always possible to find a substance that refracts light less. Ibn Sahl agrees with **Aristotle**, however, that the heavenly spheres are indeed more transparent than any sublunar substance such as crystal. It is this work that Ibn al-Haytham cites in his short treatise *Discourse on Light*.

Very much connected with this treatise is another of Ibn Sahl's works, this one on burning mirrors. In it he addresses the question of how to design not just mirrors but lenses that will focus incoming light rays at a given distance. He distinguishes between the cases in which the incoming rays originate from a source such as the Sun, which may be considered to be at an infinite distance, or from a source at a finite distance. Ibn Sahl considers both the theoretical and the practical aspects of this problem, which in the case of lenses demands consideration of refraction. And he states a geometrical relation between incident and refracted rays that, rewritten in modern trigonometric notation, is equivalent to the Law of Refraction, although it does not involve the notion of the refractive index of a medium.

In his commentary on Kūhī's astrolabe treatise, Ibn Sahl discusses the different possibilities for an astrolabe formed by projecting the sphere on to two surfaces. He argues that since one surface must rotate smoothly over the other, and remain completely in contact with it during the rotation, such surfaces must arise as surfaces of revolution of some curve around the axis of the sphere. In addition, the curve, which may of course be a straight line, must lie in a plane containing the axis. Among the more unusual examples he mentions for surfaces of astrolabes are those of conics of revolution, such as paraboloids.

Len Berggren

Alternate name

Sahl

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Ibn al-Ṣalāḥ: Najm al-Dīn Abū al-Futūḥ Aḥmad ibn Muḥammad ibn al-Sarī ibn al-Ṣalāḥ

Born **Sumaysāṭ (Samsat, Turkey), or Hamadan, (Iran)**
Died **Damascus, (Syria), 1154**

Ibn al-Ṣalāḥ was famous for his acute understanding and critique of several Greek scientific texts that had been translated and were circulating in Arabic. By profession, Ibn al-Ṣalāḥ was a doctor. After studying and beginning his career in Baghdad, he is said to have been appointed court-physician in Mārdīn at the court of the local ruler. He later settled in Damascus, where he died.

Especially of astronomical interest is his critique of the transmission of the coordinates in **Ptolemy**'s star catalog (*Almagest* VII.5–VIII.1, dating from *circa* 150). He knew and used five different translations of the *Almagest*: one in Syriac and four in Arabic. For 88 of Ptolemy's 1,025 stars, Ibn al-Ṣalāḥ notes the mistakes in the transmitted coordinates and proposes, for most of them, better values found by him by observation and by comparison with the celestial globe. Another text relevant for astronomy is his *Treatise on Projection*. Projection here refers to the projection of the surface of the sphere on to a plane, a procedure that was of fundamental importance for the development and the construction of the astrolabe; Ptolemy's text on this topic, the *Planisphaerium*, had also been translated into Arabic. Other critical works of Ibn al-Ṣalāḥ deal with mathematical and philosophical problems. But most of his writings are still unpublished and unstudied.

Paul Kunitzsch

Alternate name

al-Ṣalāh

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Ibn al-Samḥ: Abū al-Qāsim Aṣbagh ibn Muḥammad ibn al-Samḥ al-Gharnāṭī

Born **Cordova, al-Andalus, (Spain), 979**
Died **Granada, al-Andalus, (Spain), 29 May 1035**

Ibn al-Samḥ, known also as al-Muhandis (the geometer), was a noted mathematician and astronomer in Andalusia and an important member of the school of **Maslama al-Majrīṭī** centered in Cordova. Because of political unrest, Ibn al-Samḥ fled to Granada where he lived out the rest of his life. There he worked in the service of the local chief, the Berber Ḥabbūs ibn Māksan (reigned: 1019–1038), whose Jewish Minister, Samuel ben Nagrella, was also interested in mathematics and astronomy.

Ibn al-Samḥ worked in the fields of astronomy, mathematics, and, possibly, medicine. The 14th-century historian Ibn al-Khaṭīb states that Ibn al-Samḥ wrote an essay on history, but there is no other evidence for this assertion. Ibn al-Nāshī, one of Ibn al-Samḥ's most important disciples, gives a list of nine books written by his teacher.

In astronomy, Ibn al-Samḥ, like his teacher Maslama al-Majrīṭī, composed a *zīj* (an astronomical handbook with tables) based on **Khwārizmī**'s *Sindhind*, which had been composed in 9th-century Baghdad. Ibn al-Samḥ also composed a treatise on the construction of the astrolabe and another on its use (*Kitāb al-ʿAmal bi-'l-asṭurlāb*). Although **Ibn al-Ṣaffār**'s treatise on the astrolabe gained more popularity, this long book (129 chapters on the use of the instrument) is the most complete tract written in the Iberian Peninsula during the Middle Ages. The text is especially interesting because it deals with questions not usually analyzed in works of this kind, such as the visibility of the Moon and its latitude and longitude. His *Kitāb al-ʿAmal* is also important because in it he quotes an unknown work by **Ḥabash al-Ḥāsib**, clear evidence that this eastern astronomer was known in Andalusia at the end of the 10th century. The text also shows that the school of Maslama knew and used the works of **Battānī**. The *Kitāb al-ʿAmal* was the source of a treatise on the use of the spherical astrolabe composed at the court of **Alfonso X**. Since the king's astronomers did not have an Arabic text on the spherical astrolabe from which to make the Castilian translation, they took Ibn al-Samḥ's treatise and made an adaptation of it. His treatise on the construction of the equatorium – an instrument originally conceived in Andalusia and later developed in Latin Europe – is another of Ibn al-Samḥ's major contributions to astronomy. Indeed, this treatise is the first known work dealing with this instrument and was followed by works written by **Zarqāli** and **Abū al-Ṣalt** of Denia. The instrument described by Ibn al-Samḥ is a hybrid astrolabe/equatorium, and his treatise is preserved in the Alfonsine translation included in the *Libros del Saber de Astronomia*. Ibn al-Samḥ gives the numerical parameters necessary for the construction of the instrument and uses Battānī's values for the longitudes of the apogees of the planets, Khwārizmī-Maslama's values for the ascending nodes of the planets, and the eccentricities and radii of the epicycles of the planets from the *Almagest*. The equatorium has eight plates (one for the Sun, six for the deferents of the Moon and the five planets, and one for the planetary epicycles) carefully explained and placed within the mater of an astrolabe. This instrument helps to determine the longitude of a planet and saves astronomers a great deal of time, especially considering that one of their main aims in the Middle Ages was to cast a horoscope. The historian Ibn Khaldūn mentions that Ibn al-Samḥ wrote an abstract of the *Almagest*.

Ibn al-Samḥ is well known for his many compositions in mathematics. His range of subject matter includes calculation, numbers, commercial arithmetic, theory of proportions, arithmetical operations, and the solution of quadratic and cubic equations. His work in geometry includes a commentary on the book of Euclid, and a general treatise that includes an important study of straight, curved, and broken lines. The latter is partially extant in a Hebrew translation.

Mònica Rius

Alternate name

al-Samḥ

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Ibn al-Shāṭir: ˁAlāʾ al-Dīn ˁAlī ibn Ibrāhīm

Born **Damascus, (Syria), *circa* 1305**
Died **Damascus, (Syria), *circa* 1375**

Ibn al-Shāṭir was the most distinguished Muslim astronomer of the 14th century. Although he was head *muwaqqit* at the Umayyad mosque in Damascus, responsible for the regulation of the astronomically defined times of prayer, his works on astronomical timekeeping are considerably less significant than those of his colleague **Khalīlī**. On the other hand, Ibn al-Shāṭir, continuing the tradition of Ibn al-Sarrāj, made substantial advances in the design of astronomical instruments. Nevertheless, his most significant contribution to astronomy was his planetary theory.

In his planetary models, Ibn al-Shāṭir incorporated various ingenious modifications of those of **Ptolemy**. Also, with the reservation that they are geocentric, his models are the same as a number used by **Nicolaus Copernicus**. Ibn al-Shāṭir's planetary theory was investigated for the first time in the 1950s, and the discovery that his models were mathematically identical to those of Copernicus raised the very interesting question of a possible transmission of his planetary theory to Europe. This question has since been the subject of a number of investigations, but research on the astronomy of Ibn al-Shāṭir and of his sources, let alone on the later influence of his planetary theory in the Islamic world or Europe, is still at a preliminary stage. It is known, however, that Copernicus' Mercury model is that of Ibn al-Shāṭir and that Copernicus did not properly understand it.

Ibn al-Shāṭir appears to have begun his work on planetary astronomy by preparing a *zīj*, an astronomical handbook with tables. This work, which was based on strictly Ptolemaic planetary theory, has not survived. In a later treatise entitled *Taˁlīq al-arṣād* (Comments on observations), he described the observations and procedures with which he had constructed his new planetary models and derived new parameters. No copy of this treatise is known to exist in the manuscript sources. Later, in *Nihāyat al-su'l fī taṣḥīḥ al-uṣūl* (A final inquiry concerning the rectification of planetary theory), Ibn al-Shāṭir presented the reasoning behind his new planetary models. This work has survived. Finally, Ibn al-Shāṭir's *al-Zīj al-jadīd* (The new astronomical handbook), extant in several manuscript copies, contains a new set of planetary tables based on his new theory and parameters.

Several works by the scholars of the mid-13th century observatory at Marāgha are mentioned in Ibn al-Shāṭir's introduction to this treatise, and it is clear that these were the main sources of inspiration for his own non-Ptolemaic planetary models.

The essence of Ibn al-Shāṭir's planetary theory is the apparent removal of the eccentric deferent and equant of the Ptolemaic models, with secondary epicycles used instead. The motivation for this was at first sight aesthetic rather than scientific, but his major work on observations is not available to us, so this is not really verifiable. In any case, the ultimate object was to produce a planetary theory composed of uniform motions in circular orbits rather than to improve the bases of practical astronomy. In the case of the Sun, no apparent advantage was gained by the additional epicycle. In the case of the Moon, the new configuration to some extent corrected the major defect of the Ptolemaic lunar theory, since it considerably reduced the variation of the lunar distance. In the case of the planets, the relative sizes of the primary and secondary epicycles were chosen so that the models were mathematically equivalent to those of Ptolemy.

Ibn al-Shāṭir also compiled a set of tables displaying the values of certain spherical astronomical functions relating to the times of prayer. The latitude used for these tables was 34°, corresponding to an unspecified locality just north of Damascus. These tables display such functions as the duration of morning and evening twilight and the time of the afternoon prayer, as well as standard spherical astronomical functions.

Ibn al-Shāṭir designed and constructed a magnificent horizontal sundial that was erected on the northern minaret of the Umayyad Mosque in Damascus. The instrument now on the minaret is an exact copy made in the late 19th century. Fragments of the original instrument are preserved in the garden of the National Museum, Damascus. Ibn al-Shāṭir's sundial, made of marble and a monumental 2 m × 1 m in size, bore a complex system of curves engraved on the marble that enabled the *muwaqqit* to read the time of day in equinoctial hours since sunrise or before sunset or with respect to either midday or the time of the afternoon prayer, as well as with respect to daybreak and nightfall. The gnomon is aligned toward the celestial pole, a development in gnomonics usually ascribed to European astronomers.

A much smaller sundial forms part of a compendium made by Ibn al-Shāṭir, now preserved in Aleppo. It is contained in a box called *ṣandūq al-yawāqīt* (jewel box), measuring 12 cm × 12 cm × 3 cm. It could be used to find the times (*al-mawāqīt*) of the midday and afternoon prayers, as well as to establish the local meridian and the direction of Mecca.

Ibn al-Shāṭir wrote on the ordinary planispheric astrolabe and designed an astrolabe that he called *al-āla al-jāmiˁa* (the universal instrument). He also wrote on the two most commonly used quadrants, the astrolabic and the trigonometric varieties. Two special quadrants that he designed were modifications of the simpler and ultimately more useful sine quadrant. One astrolabe and one universal instrument actually made by Ibn al-Shāṭir survive.

A contemporary historian reported that he visited Ibn al-Shāṭir in 1343 and inspected an "astrolabe" that the latter had constructed. His account is difficult to understand, but it appears that the instrument was shaped like an arch, measured three-quarters of a cubit in length, and was fixed perpendicular to a wall. Part of the instrument rotated once in 24 hours and somehow displayed both the equinoctial and the seasonal hours. The driving mechanism was not visible and probably was built into the wall. Apart from this obscure reference we have no contemporary record of any continuation of the sophisticated tradition of mechanical devices that flourished in Syria some 200 years before his time.

Later astronomers in Damascus and Cairo, none of whom appear to have been particularly interested in Ibn al-Shāṭir's non-Ptolemaic models, prepared commentaries on, and new versions of, his *zīj*. In its original form and in various recensions, this work was used in both cities for several centuries. His principal treatises on instruments remained popular for several centuries in Syria, Egypt, and Turkey, the three centers of astronomical timekeeping in the Islamic world. Thus Ibn al-Shāṭir's influence in later Islamic astronomy was widespread but, as far as we can tell, unfruitful. On the other hand, the reappearance of his planetary models in the writings of Copernicus, especially his misunderstood Mercury model, is clear evidence of the transmission of some details of these models beyond the frontiers of Islam.

David A. King

Alternate name

al-Shāṭir

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Ibn Sid: Isaac ibn Sid

Flourished **Toledo, (Spain), *circa* 1250**

Ibn Sid is believed to have played an important role in the observations and other research sponsored by **Alfonso X** of Castille, all of which bore fruit in the *Alfonsine Tables*. Some of his observations are mentioned by **Isaac Israeli**, another Jewish astronomer from Toledo, who worked nearly a century after Ibn Sid. Otherwise, nothing is known about this figure.

Y. Tzvi Langermann

Alternate name

Sid

Selected Reference

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Ibn Sīnā: Abū ʿAlī al-Ḥusayn ibn ʿAbdallāh ibn Sīnā

Born **Afshana (near Bukhārā, Uzbekistan), 980**
Died **Hamadhān, (Iran), 1037**

Ibn Sīnā, also known as Avicenna, is renowned for his great works in philosophy and medicine. He was also interested in the mathematical sciences, and he dealt with a number of problems related to astronomy and cosmology that had an impact on later astronomical work in Islamic regions and in Europe.

Ibn Sīnā lived a full and colorful life and left an autobiography that was completed by his associate **Abū ʿUbayd al-Jūzjānī**. Here we emphasize his astronomical career. Ibn Sīnā lived in Bukhārā between 985 and 1005 where he studied **Ptolemy**'s *Almagest* at an early age, basically being self-taught. It is said that he had access to the library of Nūḥ ibn Manṣūr (died: 997), which included many books by the "Ancients." Ibn Sīnā lived in Gurganj from 1005 to 1012 where he wrote *Station of the Earth*. He then resided in Jurjān (1012–1014), and during that brief period he wrote his *Comprehensive Observations*, a treatise on the *Correction of the Longitude of Jurjān*, and his *Summary of the* Almagest (which he probably later incorporated into *al-Shifāʾ*, his great philosophical encyclopedic work). It was here that Jūzjānī began studying the *Almagest* with him. In 1014–1015, Ibn Sīnā moved to Rayy and then on to Hamadhān (1015–1024), where he wrote several parts of the *Shifāʾ*. He lived his final years in Iṣfahān, where he completed the final parts of the *Shifāʾ*, including the *Almagest*, composed the *Najāt* (the abridgement of the *Shifāʾ* that included logic, natural philosophy, and theology), and wrote his treatise on *Astronomical Instruments* during periods of observation for the ruler ʿAlāʾ al-Dawla. After Ibn Sīnā's death, Jūzjānī added supplemental treatises on astronomy and mathematics to his *Najāt*.

There are many astronomical works associated with Ibn Sīnā, but nine can be identified as authentic, and these can be classified into four general categories: summaries of Ptolemy's *Almagest*, works on instruments and observational astronomy, philosophical and cosmological works, and miscellaneous works.

(1) Ibn Sīnā’s *Taḥrīr al-majisṭī* is an extensive summary of the *Almagest*. Composed in Jurjān between 1012 and 1014, he later revised it, and it became Part 4 of the mathematical section of the *Shifā’*. Two works of Ibn Sīnā that are often treated as separate treatises but are really part of the above work are:

  (a) his *Ibtidā’ al-maqāla al-muḍāfa ilā mā ikhtaṣara min kitāb al-majisṭī mimmā laysa yadullu ˁalayhī al-majisṭī* (Beginning of the treatise appended to the summary of the *Almagest* containing what is not indicated in the *Almagest*). Ibn Sīnā states: “it is incumbent upon us to bring that which is stated in the *Almagest* and what is understood from Natural Science into conformity.” Among the topics included are the dynamics of celestial motion, a mathematical examination of the implications of the theoretical construction of **Ibrāhīm ibn Sinān** (who is unnamed) that would account for the discrepancies between Ptolemy’s precessional rate and his obliquity, and those of 9th-century Islamic astronomers (Ibn Sīnā gives his own observed value of the obliquity as 23;33,30°); the motion of the solar apogee, taken to be fixed by Ptolemy, and a proposal to explain its motion; and, the problem of latitude brought about by the epicycle poles.

  (b) his *Fī an laysa li-’l-arḍ ḥarakat intiqāl* (That the Earth does not have local motion), where Ibn Sīnā gives an account of Ptolemy’s arguments against the possibility of the Earth’s rotation but indicates that they are inadequate.

(2) Ibn Sīnā’s *al-Arṣād al-kulliyya* (Comprehensive observations) was written in Jurjān (between 1012 and 1014) for Abū Muḥammad al-Shīrāzī and incorporated by Jūzjānī into Ibn Sīnā’s *Najāt* after his death. This short work contains nine chapters and was translated into Persian as *Raṣadhā kullī* in the *Dānishnāmah-i ˁilā’ī*. Ibn Sīnā states that he wishes to “abridge the explication of the comprehensive observations from which one learns the general principles regarding the configuration of the orb and the calculation of the motions.”

(3) Ibn Sīna wrote *Maqāla fī al-ālāt al-raṣadiyya* (Treatise on astronomical instruments) in Iṣfahān sometime between 1024 and 1037, during his period of observations for ˁAlā’ al-Dawla. This work indicates a practical side to Ibn Sīnā’s astronomical interests and also demonstrates his interest in precision.

(4) *Fīṭūl Jurjān* ([Correction of the] longitude of Jurjān) was written in Jurjān (1012–1014) and dedicated to Zarrayn Kīs, daughter of Amīr Qābūs (= Shams al-Maˁālī). It is not extant but is discussed by **Bīrūnī** in his *Taḥdīd al-amākin*, disparaging Ibn Sīnā’s abilities in practical astronomy.

(5) *al-Samā’ wa-’l-ˁālam* (*De caelo et mundo*) was written for Abū al-Ḥusayn Aḥmad al-Sahlī [Suhaylī?]. Most likely, this is what later became the chapter of the same name in the *Shifā’*.

(6) *Maqāla fī al-ajrām al-samāwiyya (al-ˁulwiyya)* (Treatise on the celestial bodies). Like (5), this work is written from the perspective of cosmology/natural philosophy, not mathematical astronomy.

(7) *ˁIllat qiyām al-arḍ fī ḥayyizihā (fī wasaṭ al-samā’)* (On the cause of the Earth’s remaining in its position [in the middle of the heavens] = Station of the Earth). It was written in Gurganj (*circa* 1005–1012), and dedicated to al-Sahlī to whom al-*Samā’ wa-’l-ˁālam* is also dedicated.

(8) *Maqāla (Risāla) fī ibṭāl ˁilm (aḥkām) al-nujūm* (Essay on the refutation of astrology) or *Risāla fī al-radd ˁalā al-munajjimīn* (Treatise replying to the astrologers). This treatise attacks astrology and, along with his work on the categorization of the sciences, demonstrates Ibn Sīnā’s attempt to demarcate astronomy from astrology.

(9) *Maqāla fī khawāṣṣ khaṭṭ al-istiwā’* (Essay on the characteristics of the Equator). This work is no longer extant but Ibn Sīnā’s position that the equatorial region is the most temperate is known from his *Canon on Medicine* and from his critics, which included Bīrūnī, Fakhr al-Dīn al-Rāzī, and **Naṣīr al-Dīn al-Ṭūsī**.

Some of the works associated with Ibn Sīnā are misattributions, uncertain works, or duplications (due to longer or slightly different titles). (For details, see Ragep and Ragep.)

Ibn Sīnā’s astronomical knowledge and works may be viewed as less developed than those of his contemporaries such as **Ibn al-Haytham** and Bīrūnī; nevertheless, he had an impact upon later writers, and several general points can be made about his astronomical work.

First, Ibn Sīnā shows a remarkable interest in observational astronomy. Later writers refer to his observation of a Venus transit of the Sun, when it was seen as a mark on its face. This helped him establish that Venus was, at least sometimes, below the Sun. He also gave a new obliquity observation of 23;33,30° and provided a new longitude distance for Jurjān, from Baghdad, of 9;20° (compared with the traditional value of 8;0° and the modern value of 10;3°). Ibn Sīnā’s treatise on instruments includes a description of a large instrument with an improved sighting system that theoretically could provide considerably improved accuracy. Also, his summaries tend to emphasize the role of observation. Noteworthy as well are Ibn Sīnā’s criticisms of the poor instruments and observations of Ptolemy and **Hipparchus**.

Second, Ibn Sīnā’s cosmological writings are more within the tradition of natural philosophy rather than mathematical astronomy, and there is no extant work (and none reported) that one could call *hay’a* work (*i. e.*, one that provided a physical account of the mathematical models of the *Almagest*). One can therefore understand his concern with the dynamics of celestial motion and his reliance on natural philosophy to criticize Ptolemy’s attempt to rely strictly upon empirical evidence to disprove the possible rotation of the Earth. He is also aware of violations of the accepted physics in Ptolemy’s models as well as the need for reforming the Ptolemaic system and reconciling physics with mathematical astronomy.

Finally, Ibn Sīnā plays a significant role in redefining and recategorizing astronomy. He demarcates exact mathematical astronomy (*ˁilm al-hay’a*) from astrology, which he views as being part of natural philosophy.

Sally P. Ragep

Alternate names

Avicenna
Sīnā

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Ibn Ṭufayl: Abū Bakr Muḥammad ibn ˁAbd al-Malik ibn Muḥammad ibn Muḥammad ibn Ṭufayl al-Qaysī

Born **Guadix, Purchena, or Tíjola, (Spain), beginning of the 12th century**
Died **Marrakech, (Morocco), 1185/1186**

Ibn Ṭufayl was one of the Spanish philosophers who objected to major parts of the Ptolemaic system. We have little information about Ibn Ṭufayl's formative period and early days. He seems to have worked for local rulers till he became secretary to the governor of Ceuta and Tangier, thus entering the service of the Almohads, the North African dynasty that ruled Muslim Spain (al-Andalus) and North Africa from the middle of the 12th century onward. He then became court physician and counselor to the caliph Abū Yaˁqūb Yūsuf, a sovereign who loved and supported science and thought. In this post, Ibn Ṭufayl seems to have promoted most of the scientific and philosophical enterprises that characterize this period, encouraging his disciples to develop his suggestions. We know that he inspired **Ibn Rushd**'s systematic commentary of **Aristotle** and, perhaps, his writing of a medical manual. As for astronomy, **Biṭrūjī** informs us in his *Kitāb al-Hay'a* that Ibn Ṭufayl conceived a cosmological system (*hay'a*) that described planetary motion without having recourse to Ptolemaic eccentrics and epicycles, which violated the Aristotelian principles of uniform and circular motions centered on the Earth. Biṭrūjī goes on to say that Ibn Ṭufayl promised to write a book about his system, but, as far as we know, he never did so. This information is the only evidence of Ibn Ṭufayl's concern with this question, and, in spite of its brevity, is consistent with our knowledge of the "Andalusian revolt against **Ptolemy**." On the one hand, Ibn Ṭufayl was aware of the works of the philosopher who paved the way for this "revolt," **Ibn Bājja**; on the other hand, his closest disciple, Ibn Rushd, devoted much time and effort to studying the problem. Nonetheless, whatever intuitions Ibn Ṭufayl may have had, he must have kept his alternative system to himself because Ibn Rushd does not mention a single idea of Ibn Ṭufayl on the matter, and Biṭrūjī states that his *Kitāb al-Hay'a*, the only cosmological proposal deriving from this "revolt," was the result of his own efforts and research.

Ibn Ṭufayl's most important work, the philosophical romance *Risālat Ḥayy ibn Yaqẓān*, has several references to astronomy. As is well known, the book describes the process of self-education by a child Ḥayy, either the son of a princess or born by spontaneous generation, who grows up abandoned on a desert island. By means of his own understanding, he is able to discover all kinds of truth and knowledge: technical, physical, philosophical, and spiritual. The study of the heavens plays an essential role in Ḥayy's inquiries; he is able to ascertain the mechanics of celestial bodies without the help of others. The paragraphs devoted to this question mainly deal with the philosophical sides of cosmology (the souls of celestial bodies, their influence on the sublunary world, *etc.*) to the extent that it is difficult to deduce anything really useful from them about Ibn Ṭufayl's astronomical thought. Nevertheless, a passage in which he mentions that the celestial bodies can move either around their own center or around another center suggests that, in spite of what Biṭrūjī says, the author may have accepted eccentrics at some stage, thus sharing the opinion of Ibn Bājja.

Miquel Forcada

Alternate names

Abubacer
Tufayl

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Ibn Yūnus: Abū al-Ḥasan ˁAlī ibn ˁAbd al-Raḥmān ibn Aḥmad ibn Yūnus al-Ṣadafī

Died **(Egypt), 1009**

Ibn Yūnus was one of the greatest astronomers of medieval Islam and the most important astronomer of medieval Egypt. Unfortunately, nothing of consequence is known about his early life or education. As a young man he witnessed the Fatimid conquest of Egypt and the founding of the new city of Cairo in 969. In the period up to the reign of Caliph al-ˁAzīz (975–996), he made astronomical observations that were renewed by order of Caliph al-Ḥākim, who succeeded al-ˁAzīz in 996 at the age of 11 and was much interested in astrology. Ibn Yūnus's recorded observations continued until 1003.

Ibn Yūnus's major work was a monumental *zīj* or astronomical handbook with tables. Three substantial fragments of it survive in three manuscripts in Leiden, Oxford, and Paris. The *Ḥākimī Zīj*, dedicated to the caliph, is distinguished from all other extant *zīj*es by beginning with a list of observations made by Ibn Yūnus and others made by some of his predecessors. Despite his critical attitude toward these earlier scholars and his careful recording of their observations and some of his own, he completely neglects to describe the observations that he used in establishing his own planetary parameters; nor does he indicate whether he used any instruments for these observations. In view of the paucity of this information, it is remarkable that the statement that Ibn Yūnus worked in a "well-equipped observatory" is often found in popular accounts of Islamic astronomy. A. Sayılı has shown how this notion gained acceptance in Western literature.

Ibn Yūnus's *Zīj* was intended to replace the *Mumtaḥan Zīj* of **Yaḥyā ibn Abī Manṣūr**, prepared for the ˁAbbāsid Caliph **Ma'mūn** in Baghdad almost 200 years earlier. When reporting his own observations, Ibn Yūnus often compared what he observed with what he had computed using the *Mumtaḥan* tables.

The observations Ibn Yūnus described are of conjunctions of planets with each other and with Regulus, solar and lunar eclipses, and equinoxes; he also records measurements of the obliquity of the ecliptic (Chapter 11) and of the maximum lunar latitude (Chapter 38).

In spherical astronomy (Chapters 12–54), Ibn Yūnus reached a very high level of sophistication. Although none of the several hundred formulae that he presents is explained, it seems probable that most of them were derived by means of orthogonal projections and analemma constructions, rather than by the application of the rules of spherical trigonometry that were developed by Muslim scholars in Iraq and Iran during the 10th century.

The chapters of the *Zīj* dealing with astrological calculations (77–81), although partially extant in an anonymous abridgment of the work preserved in Paris, have never been studied. Ibn Yūnus was famous as an astrologer and, according to his biographers, devoted much time to making astrological predictions.

Ibn Yūnus's second major work was part of the corpus of spherical astronomical tables for timekeeping used in Cairo until the 19th century. It is difficult to ascertain precisely how many tables in this corpus were actually computed by Ibn Yūnus. Some appear to have been added in the 13th and 14th centuries. The corpus exists in numerous manuscript sources, each containing different arrangements of the tables or only selected sets of tables. The best copies are two manuscripts now in Dublin and Cairo. In its entirety the corpus consists of about 200 pages of tables, most of which contain 180 entries each. The tables are generally rather accurately computed and are all based on Ibn Yūnus's values of 30° 0′ for the latitude of Cairo and 23° 35′ for the obliquity of the ecliptic. The main tables in the corpus display the time since sunrise, the time remaining to midday, and the solar azimuth as functions of the solar altitude and solar longitude; entries are given for each degree of both arguments, and each of the three sets contains over 10,000 entries. The remaining tables in the corpus are of spherical astronomical functions, some of which relate to the determination of the five daily prayers of Islam. The impressive developments in astronomical timekeeping in 14th-century Yemen and Syria, particularly the tables of **Abū al-ˁUqūl** for Taiz and **Khalīlī** for Damascus, also owe their inspiration to the main Cairo corpus.

It is clear from a contemporaneous biography of Ibn Yūnus that he was an eccentric, careless, and absent-minded man who dressed shabbily and had a comic appearance. One day in the year 1009, when he was in good health, he predicted his own death in 7 days. He attended to his personal business, locked himself in his house, and washed the ink off his manuscripts. He then recited the Quran until he died – on the day he had predicted. According to his biographer, Ibn Yūnus's son was so stupid that he sold his father's papers by the pound in the soap market.

David A. King

Alternate name

Yūnus

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Ibrāhīm ibn Sinān ibn Thābit ibn Qurra

Born **Baghdad, (Iraq), 908/909**
Died **Baghdad, (Iraq), 946**

Ibrāhīm ibn Sinān was a creative scientist who, despite his short life, made numerous important contributions to both mathematics and astronomy. He was born to an illustrious scientific family. As his name suggests his grandfather was the renowned **Thābit ibn Qurra**; his father Sinān ibn Thābit was also an important mathematician and physician. Ibn Sinān was productive from an early age; according to his autobiography, he began his research at 15 and had written his first work (on shadow instruments) by 16 or 17. We have his own word that he intended to return to Baghdad to make observations to test his astronomical theories. He did return, but it is unknown whether he made his observations. Ibn Sinān died suffering from a swollen liver.

Ibn Sinān's mathematical works contain a number of powerful and novel investigations. These include a treatise on how to draw conic sections, useful for the construction of sundials; an elegant and original proof of the theorem that the area of a parabolic segment is 4/3 the inscribed triangle (**Archimedes**' work on the parabola was not available to the Arabs); a work on tangent circles; and one of the most important Islamic studies on the meaning and use of the ancient Greek technique of analysis and synthesis.

Ibn Sinān composed several astronomical works. *On the Motions of the Sun* presents his approach to the apparent motion of the Sun, including the question of the motion of the solar apogee. He includes a critical analysis of **Ptolemy** and his Arabic predecessors but apologizes for not being able to test his own theory, hoping for someone to make the relevant observations in future. In this work he also takes a stand against **Aristotle**'s authority, especially with respect to meteorological optics, accusing Aristotle's supporters of adopting his positions without question. Ibn Sinān evidently wrote on the trepidation of the equinoxes, a theory that he combined with a variable obliquity of the ecliptic. Though this work has not survived, later writers ascribe such a theory to him and there are hints of it in his work *On the Motions of the Sun*. Ibn Sinān's theory explaining an apparent variation in the obliquity of the ecliptic did not impress **Bīrūnī** sufficiently to change his position that the obliquity is constant. Another treatise by Ibn Sinān, *The Determination of the Anomalies of Saturn, Mars, and Jupiter*, contains a critique of Ptolemy's models of the motions of the planets.

Like his grandfather, Ibn Sinān wrote a book on shadow instruments (such as sundials and gnomons). It contains discussions of sundials erected on plane surfaces, errors in the application of sundials, how one might use a sundial as a replacement for the astrolabe, and how to draw time lines on various surfaces.

A short tract, *On the Astrolabe*, must have been written late in life, since it is not included in Ibn Sinān's own summary of his works. In it he proves the fundamental theorem of stereographic projection required to construct an astrolabe, namely that circles on the sphere (other than those that pass through the pole) are mapped to circles in the plane.

Glen Van Brummelen

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Ihle, Abraham

Born **probably Leipzig, (Germany), 14 June 1627**
Died **Leipzig, (Germany), *circa* 1699**

Though he did not know it, Leipzig postman Abraham Ihle was probably the first person to eye a globular star cluster when he discovered M22 in 1665. **Johannes Hevel** may have observed it earlier.

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I-Hsing

➜ **Yixing**

Ingalls, Albert Graham

Born **Elmira, New York, USA, 16 January 1888**
Died **Cranford, New Jersey, USA, 13 August 1958**

Together with **Russell Porter**, Albert ("Unk") Ingalls launched amateur telescope making in the United States in the 1920s. In doing so, they fathered the modern era of amateur astronomy by demonstrating how ordinary people could produce first-class telescopes through their own labor. The next revolution took place in the 1950s and 1960s when high-quality, affordable commercial telescopes became widely available. The latest phase began in the 1990s when the amalgamation of CCDs, the internet, and powerful home computers took amateur astronomy to previously unimagined heights.

Ingalls was arguably the most influential promoter of telescope making because of his editorial affiliation with *Scientific American.* In fact, he was an evangelist, stating that with the aid of Porter and others he would "attempt to popularize amateur telescope making as a widespread hobby." For about 30 years, beginning in 1925, Ingalls published articles on the topic in the magazine and conducted a regular column. In 1926 the first volume of the classic *Amateur Telescope Making* trilogy appeared under *Scientific American*'s imprint and his editorship. The subsequent volumes were first published in 1937 and in 1953. During the Great Depression of the 1930s, Ingalls recruited thousands of individuals who were attracted to amateur telescope making because, with limited resources, they could produce a working scientific instrument capable of revealing the beauties of the night sky as they had never before known. Some telescope makers were attracted to astronomy from a scientific as well as an esthetic point of view and became active contributors to organizations like the American Association of Variable Star Observers [AAVSO]. Many such individuals later went into engineering and scientific professions including astronomy.

Ingalls also gave Porter a pulpit. Today Porter is better remembered because of his pivotal role in founding what became Stellafane (which began in 1926 and continues as an annual telescope enthusiasts' convention in Springfield, Vermont) and proposed many novel ideas on instruments. Later, as a design draftsman, Porter participated in the Palomar 200-in. telescope project.

Ingalls graduated from Cornell University in 1914, served in World War I, and was a member of the *Scientific American* staff from 1923 until his retirement in 1955. During World War II he helped organize amateur telescope makers to produce special prisms for military instruments, an important activity at the time.

Leif J. Robinson

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Innes, Robert Thorburn Ayton

Born **Edinburgh, Scotland, 10 November 1861**
Died **Surbiton, Surrey, England, 13 March 1933**

Scottish–Australian–South African observational astronomer Robert Innes discovered more than 1,600 double (binary) stars; compiled a definitive catalog of double stars discovered from the Southern Hemisphere; and discovered Proxima Centauri, the third, very faint component of the closest star system. He was the eldest of 12 children of John and Elizabeth (*née* Ayton) Innes, and showed early promise in mathematics, but left school at age 12 on account of practical concerns. Thereafter he was entirely self–taught. In 1884 Innes married Anne Elizabeth Fennell; they had three sons. The couple moved to Sydney, Australia, where Innes was to become a successful wine merchant. Under clear Australian skies his passion for astronomy blossomed. W. F. Gale lent him a Cooke refractor, and he began a search for southern double stars. Innes corresponded with astronomer **David Gill**, which eventually led Gill to offer him the position of secretary at the Royal Observatory, Cape of Good Hope. Accepting the position meant a significant reduction in his income, but the prospect of a career in astronomy was too good to pass up. Innes and the family arrived in South Africa in 1896. At first his duties were entirely clerical. He nonetheless found time to compile a catalog of southern double stars and revise the *Cape Photographic Durchmusterung.* When the Transvaal (Meteorological) Observatory was founded at Johannesburg in 1903, Gill recommended Innes for its directorship. Innes successfully lobbied the government to make astronomy a greater part of the observatory's work. In 1897 the facility acquired a 9-in. telescope. Two years later an order was placed for a 26.5–in. refractor (though the telescope was only delivered in 1925), and by 1912 the institution was renamed the Union Observatory and took on a purely astronomical mission. During Innes's administration the observatory established its position among international centers of astronomical research. Innes especially nurtured ties with the Leiden Observatory. **Willem de Sitter** and **Ejnar Hertzsprung** were among his guest observers at Johannesburg.

Innes himself enjoyed very keen eyesight. He is credited with the visual discovery of 1,628 double stars; he discovered numerous variable stars and carried out extensive observations of phenomena of the Galilean satellites of Jupiter, including the codiscovery of the corotation of one of the satellites. Yet he was not an old-style visual astronomer. He advocated photographic astrometry and pioneered the use of the blink microscope for measuring stellar proper motions. With this instrument Innes detected the large proper motion of Proxima Centauri and identified this star as the nearest neighbor of the Solar System. It was also the faintest star known for a brief period of time.

Remarkably, although he had no formal training in higher math, Innes was a master of astronomical calculation. Through a reduction of all observed transits of Mercury between 1677 and 1924, he was among the first to demonstrate the slowing of the Earth's rotation. This was confirmed 2 years later by **Ernest Brown** and independently discovered from ancient eclipse data by Lord Fotheringham of Oxford. Innes also calculated the elements of many binary star systems.

Innes was renowned for his engaging in unconventional habits, such as his refusal to wear a tie even on formal occasions, and also for the warmth of his Scottish hospitality and the breadth of his abilities. He was a leading member of the South African Association for the Advancement of Science, as well as a fellow of the Royal Astronomical Society and the Royal Society of Edinburgh. Leiden University conferred upon him a doctorate, *honoris causa*, in 1923. He retired from the Union Observatory in 1927 and died suddenly after a long life of robust health.

Keith Snedegar

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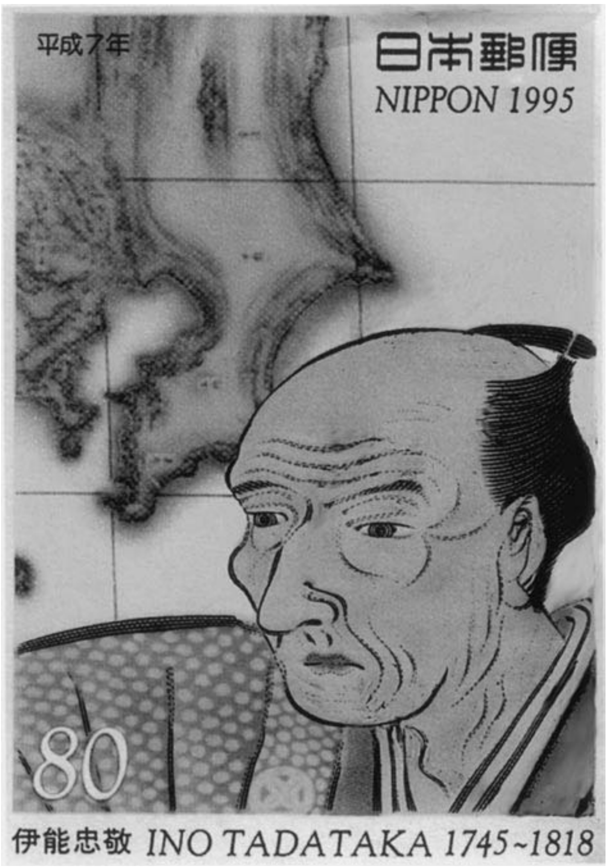
Ino, Tadataka

Born **Kazusa, (Chiba Prefecture), Japan, 1745**
Died **Edo, (Tokyo), Japan, 1818**

Tadataka Ino contributed to terrestrial cartography by making careful measurements of longitude and latitude. He was born Sanjiro Jinbo, but when adopted in 1765 by a merchant family named Ino, his first name was changed to Saburozaemon. His new family lived in the town of Sawara in Shimousa Province (present-day Sawara in Chiba Prefecture). As he reached maturity and began pursuing more advanced study, his first name was once again changed, this time to Tadataka.

The first stage of Ino's life was dedicated to gaining some measure of social status and financial independence, and to raising a family. At this point, he devoted only spare time to what was described as his secret passions – astronomy and the study of calendars.



In the *Edo* period (1603–1867), merchant classes took the lowest position in a social hierarchy that placed *Samurai* first, followed by farmers, engineers, and merchants in that order. Because of public and community contributions, Ino was promoted to the *Samurai* class in 1783. In 1795, at age 50, he turned over a successful business to his son and retired to Fukagawa in Edo. Only then did he begin to pursue his interest in astronomy and calendar studies full time and become a pupil of the famous *Tokugawa*-appointed astronomer and calendar scholar, **Yoshitoki Takahashi**. Though Ino was 19 years older than Takahashi, he was a dedicated student and mastered techniques of land survey as well as calendar making and astronomical observation using mechanical instruments that he was able to purchase.

Both Ino and Takahashi were interested in improving the accuracy of latitude and longitude measurements. While Ino initially tried to pursue this interest in local Fukagawa, Takahashi suggested that Ino expand his efforts to include larger geographical areas. After successfully completing a preliminary survey of land ranging from Tokyo to provinces in the north, Ino received official approval from a Shogunate concerned with external incursion to initiate a more comprehensive nationwide land survey. He worked on this project for 17 years. Ino died while still working on the map based on data he gathered. He had a great respect and appreciation for his teacher and mentor Takahashi and requested that his tomb be constructed next to his beloved teacher who had passed away some years earlier. They rest next to each other in the compound of the *Genku* temple in Asakusa, Tokyo.

Ino's contributions were of great importance in the development of pragmatic applications of astronomical techniques.

Ino appears to have been the first person in Japan to observe a culmination of Venus (1797). But without doubt his greatest legacy is found in the production of the multivolume *Dai Nihon Enkai Jissoku Zenzu* (Complete records of an actual survey of the Japanese coast), which appeared posthumously in 1821. His maps, popularly referred as *Ino Zu*, served as a basis for cartography in Japan through the *Meiji* Period (1868–1912) and were used as late as 1924. These maps were based on accurate astronomical observations and the charting of the Japanese coastline. Ino was able to measure longitudinal distance to within an accuracy of 1 min. Records indicate that he walked more than 40,000 km during his quest for accurate maps, a distance exceeding the circumference of the Earth. By the age of 70, Ino had spent some 3,737 days surveying Japan.

With the guidance of Takahashi, Ino's use of precise measurement techniques were valuable not only in cartography but in the development of astronomical data necessary for accurate calendar construction. He was able to adjust for survey errors spanning large distances and measured the latitude and longitude of major cities and strategic points throughout the country. Because he included a rational correspondence between astronomical observation and terrestrial location, Ino is considered to be the first Japanese cartographer to use western scientific methods in his survey of Japan.

Steven L. Renshaw and *Saori Ihara*

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Irāq

➔ **Ibn ʾIrāq**

Irwin, John Henry Barrows

Born **Princeton, New Jersey, USA, 7 July 1909**
Died **Tucson, Arizona, USA, 20 April 1997**

American astronomer John Irwin pursued a method for determining which was the near edge, and which was the far edge, of spiral galaxies. He found that spiral arms "trail."

In 1955 Irwin and his graduate student at Indiana University, Arthur Cox, went to South Africa to observe Cepheid variable stars in open clusters. In doing so they helped establish the zero-point of the Period–Luminosity Relation.

Irwin's major collection of historic photographs, featuring 20th-century astronomers, is now archived by the American Institute of Physics.

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Isfizārī: Abū Ḥātim al-Muẓaffar ibn Ismāʿīl al-Isfizārī

Flourished **Khurāsān, (Iran), late 11th/early 12th century**

Isfizārī, a contemporary of **ʿUmar Khayyām** and **ʿAbd al-Raḥmān al-Khāzinī**, constructed an accurate balance, composed books on mathematics and meteorology, and was inclined to the sciences of astronomy (*hay'a*) and mechanics. Few details of his biography are known. The historian Ibn al-Athīr and the astronomer **Quṭb al-Dīn al-Shīrāzī** link him to the observatory in Iṣfahān sponsored by the Saljūq king Malik-Shāh (reigned: 1072–1092). Niẓāmī-i ʿArūḍī reports that he met with Isfizārī in Balkh (in present-day Afghanistan) in 1112 or 1113 in the company of Khayyām. Finally, Khāzinī writes, in 1121–1122, that he was already deceased. The most significant extant writing of Isfizārī is his treatise *Irshād dhawī al-ʿirfān ilā ṣināʿat al-qaffān* (Guiding the learned men in the art of the steelyard), a two-part text on the theory and the practice of the steelyard balance. Three other texts constitute the rest of his scientific *oeuvre*: a summary of the so-called 14th book of Euclid's *Elements*, a text on geometrical measurements, and a treatise on meteorology in Persian.

No work of astronomy by Isfizārī has reached us. However, he was one of the astronomers of Malik-Shāh Observatory in Iṣfahān, although we do not know the exact date he joined the observatory or how long he stayed there. This observatory was one of the most important institutions of its kind in the 11th-century Islamic world. Its program of astronomical research was active for about 20 years, from 1074–1075 until 1092, terminating with the death of both Malik-Shāh and his influential minister Niẓām al-Mulk. According to Quṭb al-Dīn al-Shīrāzī, there were eight men on the staff of the observatory, which included Isfizārī, ʿUmar Khayyām, Maymūn ibn Najīb al-Wāsiṭī, Muḥammad ibn Aḥmad al-Maʿmūrī, and Abū al-ʿAbbās al-Lawkarī.

The collective work done at the Malik-Shāh Observatory was directed principally toward the reform of the solar calendar then in use in Iran. The result was the Jalālī calendar, which was one of the most accurate calendars ever devised. (For more information on this calendar, see the entry on Khayyām.)

Mohammed Abattouy

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Ishāq

➔ **Ibn Isḥāq**

Isḥāq ibn Ḥunayn: Abū Yaˤqūb Isḥāq ibn Ḥunayn ibn Isḥāq al-ˤIbādī

Born ***circa* 830**
Died **Baghdad, (Iraq), 910/911**

Isḥāq ibn Ḥunayn was one of the most important translators of Greek scientific and mathematical works into Arabic. He lived in the ˤAbbāsid capital of Baghdad during the vibrant period of the Graeco–Arabic translation movement, when nearly everything of philosophical or scientific interest from the ancient Greek corpus was translated into Arabic.

Isḥāq came from a family noted for its translations. He was the son of the most renowned translator of the period, **Ḥunayn ibn Isḥāq**, who hailed from a Nestorian Christian Arab tribe of al-Ḥīra, Iraq. Ḥunayn set the standard of excellence, professionalism, and method for Graeco–Arabic translation, which he passed on to his son. Like his father, Isḥāq was a physician and wrote an important history of physicians that supplements our information on that subject derived from classical sources. Ḥunayn reports in the epistle in which he describes the 129 works of Galen he translated or revised that he translated several books of Galen specifically for the use of his son Isḥāq, perhaps for him to study as part of his education as a physician.

Although Isḥāq was a physician, he understood mathematics and astronomy in order to be able to grasp the sophisticated arguments of Euclid’s *Elements* and **Ptolemy**’s *Almagest*, both of which he translated from Greek into Arabic. These two works, which were of immense importance for the subsequent development of Greek mathematical astronomy into the Islamic world, were Isḥāq’s primary contribution to astronomy. The *Elements* were useful not only for instruction in geometry but also as a model for presenting scientific theory systematically and deductively; it was considered by many ancient scholars the foremost example of the methods expounded by **Aristotle** in his *Posterior Analytics*. The *Almagest* was a comprehensive approach to mathematical astronomy from which a long tradition of practice, criticism, and improvement evolved in the Islamic world. Isḥāq’s translation of the *Almagest* was emended by the practicing astronomer, **Thābit ibn Qurra**, who perhaps refined the mathematical details. Though the *Elements* and the *Almagest* were translated multiple times in the 9th century, which is an indication of the ˤAbbāsid interest in the ancient Greek scientific heritage and the substantial financial support provided for translation into Arabic, it is important to note that the Isḥāq/Thābit translation became standard for both the *Elements* and the *Almagest*.

Isḥāq translated a number of other works from Greek. These included Euclid’s *Optics*; the *Spherics* of **Menelaus**; *On the Moving Sphere* by **Autolycus**; several Platonic dialogues; and works of Aristotle, including *On the Soul* and the *Physics*.

Glen M. Cooper

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Isidore of Seville

Born **Cartagena or Seville, (Spain), *circa* 560**
Died **(Spain), 636**

Isidore’s major contribution to learning was his activity as an encyclopedist or writer of compendia of Greco–Roman and Christian knowledge, which were used for centuries as textbooks.

Isidore was born in Cartagena, or Seville, Spain, in a highly educated family. His brothers Leander and Fulgentius were Bishop of Seville and Bishop of Astigi respectively, while his sister Florentina was an abbess who governed several communities of nuns. Skilled in languages, Isidore mastered Latin, Greek, and Hebrew. His prolific and popular writings, coupled with his conviction that every bishop in Spain should establish a school to teach the liberal arts, law, and medicine, earned him the title of “Doctor of the Church” and the epithets “Last of the Latin Fathers” and “Schoolmaster of the Middle Ages.” In modern times, it has been suggested that he is a patron saint of the internet.

In 599, Isidore succeeded his brother Leander as Archbishop of Seville. In this capacity, he presided over several church councils, including the Fourth Council of Toledo in 633, which enacted Isidore's proposal for the establishment of schools throughout Spain, and sought to promote tolerance of the Jewish faith. At a time in which learning was undervalued by the ruling Goths, students in Seville enjoyed an education in the seven liberal arts, known as the trivium and quadrivium, which included astronomy.

Isidore's compendium of knowledge, the *Etymologies*, remained a standard textbook well into the Renaissance. It is an encyclopedia of 20 volumes, of which nearly 1,000 medieval copies are extant. Works more focused on the natural world include *De Rerum Natura* (On the nature of things), and a work on the origin of creatures. His remaining works deal with biography, history, philosophy, and theology. *De Rerum Natura* deals with the cosmos, meteorology, and geography, among other topics. It is not presented as a work of original research, but a consolidation of classical Greek and Roman notions of the physical world, summarizing the positions of earlier natural philosophers, and posing questions for the reader about the correctness of their theories. Isidore's named sources include Ambrose, Augustine, Caspius, Ennius, Lucian, **Plato**, Priscian, and **Virgil**, whose *Aeneid* and *Georgics* are cited extensively.

Lacking tools of observational astronomy such as telescopes, philosophers of the Middle Ages and Antiquity supported their theories by logical and mathematical arguments. While Hellenic scholars knew that the Earth was round, and medieval scholars had Plato's *Timaeus* as authority for a spherical cosmos, theirs was a geocentric Universe, an orderly onion-like structure of spheres, within which planets, including the Sun, rotated about the Earth below an outer ring of stars. Classical and medieval philosophers could only explain the Universe by reference to four basic elements – earth, air, fire, and water. The acceptance of classical authority, coupled with a desire to reconcile observations with scriptural revelation, did not mean that writers like Isidore were unaware of anomalies and problems. Some of the most basic astronomical problems presented in *De Rerum Natura* involved measurement of time. Before the modern invention of standard time, the hour at which the day began was a matter of opinion. The lack of a standard made it more difficult for observers to compare their results.

The book begins by discussing the day, the night, the week, the month, the regularization of the months, the year, the seasons, and the solstices and equinoxes. It then broadens to a discussion of the wider cosmos, dealing with the world and its divisions, the sky and the motions of the planets, and related cosmological topics. These are followed by discussions of the Sun's motion and sunlight, the source of moonlight, and lunar eclipses. The courses of the stars, their names, the sources of starlight, anomalies such as comets, and a discussion of whether or not the stars are animate, occupy books 12 through 27. Isidore then turned his attention to meteorology, discussing rainbows, clouds, and winds, before moving to geological topics, such as rivers and oceans and waves, earthquakes, and volcanoes.

Isidore summarized competing arguments, sometimes remaining neutral, at other times suggesting the most plausible ones. Is there one heaven, Isidore asked, or are there several celestial spheres? Philosophers divide the sky into seven heavens or celestial spheres, demarked by the orbits of the planets. Why should there be waters in the midst of the heavens? Water must be there so that the elements in the inferior spheres are not set alight by the fires in the higher ones. Objects in the lower heavens do not move with uniform motion, as is apparent from observation.

The source of the Moon's luminescence, and its phases, preoccupied natural philosophers. Isidore apparently opted for the theory that the Moon reflects the Sun's light. Citing Augustine, Isidore recounted two classical explanations for the Moon's luminescence, but cautioned that there is doubt about which to believe. According to the first theory, the Moon is a sphere, half of which emits light, the other of which does not, and because of changes in position, we alternately see either half. If that were the case, he asked, how could we account for eclipses? Lunar eclipses are more easily explained if one holds that the Moon reflects the Sun's light, and Isidore advanced the theory of the Earth's interposing itself between them. Isidore also presented contending theories of solar eclipses: The Sun's light being blocked by the Moon, or an inherent defect in the Sun that makes it turn off every so often.

Isidore weighed arguments about the Sun's composition and decided it is fire, and will one day be consumed. The Sun seems bigger than the Moon, but it must be more distant, since it appears to be the same distance away when observed in Britain or in India. Moreover, if the Sun remained always in one place with respect to the Earth, nights and days would be equal throughout the year. It does not rise and set in the same places throughout the year.

To the medieval mind, the truths of observational science were always to be compared with the truths of revealed religion. At points, numerological desiderata override observation. There are seven phases of the Moon, just as there are seven planets, 7 week days, seven sacraments of the Church, and seven gifts of the Holy Spirit. In order that there be seven phases of the Moon, Isidore had to leave out the New Moon (that period in which the Moon is not visible at all). When dealing with observational problems, however, he did not let allegory interfere. The old calculation of the year did not add up to 365 days, because it had been based on lunar months of 30 days.

Because of the tenor of the time, in which no sharp lines demarcated different branches of learning, it is tempting for Moderns to dismiss Isidore's writings as being fraught with theology. To do so would be to cast aside the wealth of information about Greek and Roman science, and about the issues being discussed in Isidore's own time, so aptly and accessibly preserved in his writings.

C. Brown-Syed

Alternate name

Isidorus Hispalensis

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Isidorus Hispalensis

➔ **Isidore of Sevilla**

J

Jābir ibn Aflaḥ: Abū Muḥammad Jābir ibn Aflaḥ

Flourished **probably Seville, (Spain), 12th century**

Jābir ibn Aflaḥ was a mathematician and astronomer in 12th-century Andalusia, who wrote a treatise entitled *Iṣlāḥ al-Majisṭi* (Correction of the *Almagest*) in which, as the title suggests, the author made a long series of criticisms and corrections of **Ptolemy's** main astronomical treatise.

Little is known of Jābir's life. It seems that he was from Seville, since he is referred to in several sources as al-Ishbīlī. One of these sources is **Maimonides**; in his *Guide for the Perplexed*, he claims to have met Jābir's son. This reference suggests that Jābir was alive sometime between the end of the 11th century and the first half of the 12th century.

Jābir's main work is a commentary on Ptolemy's *Almagest*, a treatise that he had seen in two translations from the Greek. The *Almagest* is both the great synthesis and the culmination of mathematical astronomy of the ancient world, composed in Alexandria in the second century. It was translated into Arabic at least five times, and, from the late ninth century onward, constituted the basis of the mathematical astronomy carried out in the Islamic world.

In one of the preserved manuscripts (Berlin MS 5653), Jābir's work appears under the title *Iṣlāḥ al-Majisṭi* (Correction of the *Almagest*); in fact, it is a reworking of Ptolemy's work. Mathematical precision and proof seem to be Jābir's maximum aspiration in his *Iṣlāḥ*. It is divided into nine books. In the foreword, the author outlines the main differences between the *Iṣlāḥ* and the *Almagest*. The theorem of **Menelaus** that Ptolemy used is systematically replaced by theorems related to spherical triangles. These theorems were probably taken from mathematicians such as **Abū al-Wafā' al-Būzjānī** and **Abū Naṣr Manṣūr ʿAlī ibn ʿIrāq**, who were responsible for what has been called the "trigonometric revolution" in eastern Islam around the year 1000. In Andalusia, these theorems were formulated for the first time by **Ibn Muʿādh** at the beginning of the 11th century. Somewhat surprisingly, Jābir does not mention any Arab authors in his treatise—not even Ibn Muʿādh despite the fact that both authors were Andalusians.

Jābir's most notable divergence from Ptolemy concerns the model of the inferior planets, Venus and Mercury. Ptolemy placed them between the Moon and the Sun. He had to explain the fact that these two planets do not pass in front of the Sun by arguing that they are never on the line between the Sun and the view of the observer. Jābir affirmed that this argument was mistaken, and he placed these planets above the Sun.

Jābir criticizes Ptolemy harshly. He says that the mathematical basis of the *Almagest* should be improved, though both the parameters and some planetary models had already been modified by previous Arab astronomers.

Jābir's work is the first criticism of the *Almagest* in the Islamic West. Its focus is original, far removed from that of the Aristotelian philosophers who launched the "Andalusian Revolt" against Ptolemy or from the criticisms of the astronomers at the Marāgha Observatory in the 13th century.

Jābir's criticisms of Ptolemy bear witness to his great mathematical ability but also suggest that his grasp of more practical matters was limited. It would have been extremely difficult to obtain the observations of planets required to apply his alternative methods.

The *Iṣlāḥ* is, clearly, the work of a theoretical author. The demonstrations include neither numerical examples nor tables. However, the work describes an instrument, which the author claims, can replace the four instruments described by Ptolemy for astronomical determinations. With the exception of **Zarqālī's** armillary sphere, this is the first description in an Andalusian text of an instrument designed for astronomical observation. It is extremely large and has been considered a forerunner of the torquetum, an instrument of European tradition described for the first time in a 13th-century Latin text.

The text of the *Iṣlāḥ* was probably revised by the author himself—if not all, at least the section on trigonometry. It was later introduced in Egypt by Maimonides who, with one of his pupils, revised the text around 1185. In Andalusia, **Ibn Rushd** and **Biṭrūjī** were clearly influenced by this author.

During the 13th century the text spread in the East: a manuscript of this work, preserved in Berlin, was copied in Damascus in 1229. A summary of the text was also compiled by **Quṭb al-Dīn al-Shīrāzī**, a Persian astronomer and physicist.

Jābir's work seems to have had considerable influence upon Hebrew astronomy. There are two Hebrew translations of this work, one dating from 1274, by **Moshe ben Tibbon**, and the second by his nephew **Jacob ben Makhir**, revised in 1335 by Samuel ben Yehuda of Marseilles. Thanks to these Hebrew translations and the Latin translation, due to **Gerard of Cremona**, the text reached a wide readership in Europe.

In the Latin world, Jābir was considered a vigorous critic of Ptolemy's astronomy. His treatise helped to spread trigonometry in Europe; in the 13th century, the trigonometric theorems were used by the astronomers who compiled the *Libro del Cuadrante Sennero* (Book of the sine quadrant) working under the patronage of King **Alfonso X** the Wise. In the 14th century, **Richard of Wallingford** used the theorems in his work on the Albion. Jābir is probably the source of much of **Johann Müller**'s (Regiomontanus's) trigonometric work entitled *De triangulis* (On the triangles) although he is not mentioned. Finally, he may also be the source of the trigonometric section in **Nicolaus Copernicus**'s *De Revolutionibus* (On the revolutions [of the celestial spheres]).

Emilia Calvo

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Jacchia, Luigi Giuseppe

Born **Trieste, (Italy), 4 June 1910**
Died **Cambridge, Massachusetts, USA, 8 May 1996**

Variable star astronomer Luigi Jacchia received his Ph.D. degree in physics at the University of Bologna in 1932, where he became an instructor after graduating. Already an experienced observer of variables, he published a comprehensive work on the subject in 1933. After teaching at Bologna from 1932 to 1938, Jacchia immigrated to the United States where he was employed as a Research Assistant at Harvard College Observatory [HCO] in 1939. During World War II, Jacchia worked as scientific consultant for the United States Office of War Information, Foreign Language Broadcasting and Monitoring Service. After the war he returned to HCO but was also employed as a research associate at the Massachusetts Institute of Technology [MIT] from 1949 to 1953. In 1956, **Fred Whipple** invited Jacchia to join the newly reorganized headquarters of the Smithsonian Astrophysical Observatory [SAO] as a physicist when that organization relocated from Washington to Cambridge, Massachusetts.

As his first SAO assignment, Jacchia assisted in the planning for the International Geophysical Year [IGY] (1957–1958) by developing programs to study the density and composition of the Earth's upper atmosphere from its effects on artificial satellite motions. From his analysis of early satellite data, Jacchia developed models that related upper atmospheric drag effects on satellites to solar activity and included diurnal and other periodic effects. His models became the international standard in the field of predicting orbital life for satellites, and proved spectacularly accurate in their prediction of the fate of the Skylab space station.

After his arrival in the United States, Jacchia was an active participant in the American Association of Variable Star Observers [AAVSO]. He collaborated with AAVSO recorder **Leon Campbell**, as an author of a volume in the Harvard Books on Astronomy, *The Story of Variable Stars*. After the war, Jacchia was no longer involved in variable star work.

Michael Saladyga

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Jackson, John

Born **Paisley, Scotland, 11 February 1887**
Died **Ewell, Surrey, England, 9 December 1958**

John Jackson was His Majesty's Astronomer at the Royal Observatory, Cape of Good Hope.

Jackson was the fifth of eight children born to Matthew and Jeannie (*née* Millar) Jackson. He entered Glasgow University at the age of 16, and graduated with an M.A. in mathematics (1907), followed by a B.Sc. (1908) with special distinction in mathematics, natural philosophy, astronomy, and chemistry. Jackson then went to Cambridge University, where he obtained a first class degree in the mathematical *tripos*. His first research concerned the motion of the eighth satellite of Jupiter, which had been discovered by **Phillibert Melotte** at Greenwich in 1908.

In 1914, Jackson was appointed chief assistant at the Royal Observatory, Greenwich. He did much routine observing during World War I, especially with the Airy Transit Circle. In 1917, Jackson was commissioned in the Royal Engineers. He was sent to France as a trigonometric survey officer. After his return to Greenwich, his assignments included the preparation for publication of Greenwich observations of double stars made between 1893 and 1919, a study of the observatory pendulum clocks, the reduction of **Thomas Hornsby**'s observations made from 1774 to 1798, and examination of the motion of the perihelion of Mercury's orbit.

In 1933, Jackson was appointed His Majesty's Astronomer at the Royal Observatory, Cape of Good Hope. He supervised and participated in several large, routine programs, including determinations of the proper motions of some 41,000 southern stars in the Cape Astrographic Zones. He did much of the observing and measuring for determining the parallaxes of about 1,600 stars, selected mainly because they had appreciable proper motions. Jackson also supervised a large program of photographic astrometry. Afterward, many stellar magnitudes were determined, and this program greatly improved photometry in the Southern Hemisphere.

Jackson retired in 1950 and returned to England. His honors included the Gold Medal of the Royal Astronomical Society, whose presidency he assumed in 1953–1955. In 1920, Jackson married Mary Beatrice Marshall. They had one son who died in infancy.

Roy H. Garstang

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Jacob ben Makhir ibn Tibbon

Born **possibly Marseilles, France, *circa* 1236**
Died ***circa* 1305**

Jacob ben Makhir was a translator of Arabic scientific works into Hebrew and also wrote a few original astronomical works. Known also as Don Profeit Tibbon, he was a Jewish scholar who lived in Montpellier and other Provençal towns. He wrote exclusively in Hebrew; his extensive output included both translations into Hebrew and original compositions. Since he was known under two distinct Hebrew names, modern scholars had treated these as representing two separate persons, until Salomon Munk (*Mélanges*, p. 489, n. 3) showed they were one and the same. The Hebrew word *m^{e}kîr* means "gain" or "profit," hence the Provençal form Profeit (and many variants) and the Latin Profatius.

Jacob ben Makhir's translations were almost entirely of mathematical and astronomical works, both original Arabic tracts and Arabic versions of Greek works. These included Euclid's *Elements* and *Data*; **Autolycus**' *Moving Sphere*; **Menelaus**' *Sphere*; **Qusṭā ibn Lūqā**'s *On the Spherical Astrolabe* (al-Kura al-falakiyya); **Ibn al-Haytham**'s *On the Configuration of the World* (Fī hay'at al-ˁālam); **Ibn al-Ṣaffār**'s *On Using the Astrolabe* (al-ˁAmal bi-'l-asṭurlāb); **Jābir ibn Aflaḥ**'s Correction of the *Almagest* (Iṣlāḥ *al-Majisṭi*); and **Zarqālī**'s, *On the al-ṣafīḥa* (A development of the astrolabe plate).

Jacob ben Makhir's two original works were on the quadrant and an "almanach." His *Explanation of the Instrument Called the Quadrant of Israel* was translated widely into Latin, where it was referred to as *Quadrans Novus*; it is found in the manuscripts with various incipits (such as *quoniam scientie astronomie non completur absque instrumentis*). The work had a wide influence from the last decade of the 13th century.

The *Almanach* was known simply in Hebrew as *luḥot*, a term used for all astronomical tables. This is based directly, as the author says, on a quite similar work by Zarqālī (*circa* 1075), and calculated according to the Toledan Tables, but with a change of meridian from Toledo to Montpellier. This is not a set of tables like those found in a typical Arabic handbook (*zīj*). Rather, the true tropical positions of the Sun and the planets are given in cycles such that only small corrections are to be applied to cycles beyond the original one. In the case of the Moon, some calculations are required, but much less than when working directly from the tables of a *zīj*. The tabulation of the Sun is given in a 4-year cycle, beginning 1 March 1301, while the five planets (Saturn to Mercury) begin on 10 March 1300 (outer planets), 5 March 1301 (Venus), and 5 March 1300 (Mercury); the periods in years of the tabulations are approximately 60, 84, 80, 9, and 47 years, respectively. The tabulation of the corrected equation of the Moon is given daily from 22 March 1300 for 23 years. In these tables the amount of precession, which is represented by the "equation of the eighth sphere," has been added to the sidereal longitudes derived from the *Toledan Tables*, so as to give tropical longitudes. A table of the equation of the eighth sphere is found in manuscripts of the *Almanach*, but it is not included in the edition by Boffito d'Eril. Both this work and the *Almanach* of Zarqālī could be usefully examined in greater depth.

Jacob ben Makhir was influential long after his time, perhaps surprising in view of his extant work. For example, **Nicholas Copernicus** (*De Revolutionibus*, III, 2 and 6) attributes to him the value 23° 32′ of the obliquity for the year 1290, although this has not been traced to any surviving text.

Finally we should mention that Jacob ben Makhir also produced Hebrew versions of the works of various philosophers, including **Ibn Rushd**.

Raymond Mercier

Alternate names

Don Profeit Tibbon
Profatius

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Jagannātha Samrāṭ

Born **(India), *circa* 1657**
Died **(India), *circa* 1744**

Jagannātha, the famous Guru of Savāī **Jai Singh**, hailed originally from Maharāśtra. His father was Ganeśa, and grandfather, Viṭṭhala. At the suggestion of Jai Singh, Jagannātha studied Arabic and Persian and became proficient in both. He translated works on astronomy and mathematics from Arabic into Sanskrit. His major work, *Samrāṭ Siddhānta* or *Siddhāntasārakaustubha*, is based on **Ṭūsī's** version of the *Almagest* of **Ptolemy**; the first 13 chapters of *Samrāṭ Siddhānta* run parallel to the 13 books of the *Almagest*. Jagannātha also translated Euclid's *Elements* into Sanskrit in 1719, and the latter work is called *Rekhāgaṇita*. He compiled a glossary of technical terms in Sanskrit and composed a work on instrumentation called *Yantraprakāra*. Jagannātha was himself an observer and regarded observations as the *pramāṇa*, or deciding factor, whenever there were discrepancies between theory and observation. He admired **Ulugh Beg** and the advances in astronomy and mathematics in the Islamic world. Jagannātha did not use telescopes in his observations nor did he include telescopes in his work on astronomical instruments.

Narahari Achar

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Jaghmīnī: Sharaf al-Dīn Maḥmūd ibn Muḥammad ibn ʿUmar al-Jaghmīnī al-Khwārizmī

Flourished **Khwārizm, (Uzbekistan), first half of the 13th century**

Jaghmīnī is the author of the ubiquitous elementary astronomical text *al-Mulakhkhaṣ fī al-hay'a al-basīṭa* (Epitome of plain theoretical astronomy). This popular, simplified (*i. e.*, without proofs) introduction to astronomy, written in Arabic, was the subject of an enormous number of extant commentaries and supercommentaries. These commentaries (many written in Persian as well as Arabic) were meant to be studied along with the *Mulakhkhaṣ* and used as supplements for more advanced teaching texts.

The *Mulakhkhaṣ* is an elementary summary of the configuration of the celestial and terrestrial worlds, and the orbs and sublunar levels contained therein. It is composed of an introduction and two sections. The introduction is an explanation of the divisions of the bodies in general; Section 1 is divided into five parts and is an explanation of the celestial orbs and what pertains to them; and Section 2 is divided into three parts, and is an explanation of the Earth and what pertains to it.

It is noteworthy that *al-Mulakhkhaṣ* lacks any treatment of sizes and distances of the celestial bodies, which one typically finds in other astronomical textbooks of a similar genre. (See, for example, works by **Ṭūṣī**, **Kharaqī**, and **ʿUrḍī**.) Presumably, the difficulty of the subject matter in so elementary a textbook made its placement there inappropriate. Indeed, Jaghmīnī is purported to have written a separate treatise on the subject in a unique manuscript (Cairo, Dār al-kutub MS Ṭalʿat majāmīʿ 429/2, f. 4a–4b.).

There has been some confusion regarding Jaghmīnī's dates; he has several times been misdated as living *circa* 1344/1345 (Suter 1900, p. 164; Suter/Vernet *EI2*, p. 378; Sezgin 5: 115), in part because of confusion between him and another Jaghmīnī, a physician, who lived at that time. The date of composition of the *Mulakhkhaṣ* is given as *circa* 618 H./1221–1222 by several sources (C. Storey, D. King, and E. Ihsanoğlu). In any event, we can safely place him as living in the early 13th century due to an Istanbul manuscript (Lâleli 2141) that contains a copy dated 644 H./1246–1247.

Furthermore, there has been speculation that Jaghmīnī may have lived after Naṣīr al-Dīn al-Ṭūṣī since maximum daylight times in some copies of Jaghmīnī's text clearly derive from Ṭūṣī's *Tadhkira* (see Ragep, 2: 470–471). However, this simply represents an excellent example of how the *Mulakhkhaṣ*, as a textbook "in progress," was continuously updated and changed by commentators and copyists, especially when they felt more reliable information was available. (In this case Ṭūṣī's data were considered more correct than **Ptolemy**'s and were thus substituted for Jaghmīnī's original data.)

The educational tradition represented by the transmission, transformation, commentaries, and study of Jaghmīnī's text was thriving in the Ottoman period well into the 18th century (Ihsanoğlu, *History*, pp. 586–587). Indeed, the *Mulakhkhaṣ* tradition exists in thousands of extant copies of the original as well as commentaries, supercommentaries, and glosses. There were at least 15 commentators, including **Faḍlallāh al-ʿUbaydī Kamāl al-Dīn al-Turkmānī**, the theologian **al-Sayyid al-Sharīf al-Jurjānī**, and **Qāḍīzāde al-Rūmī**, who dedicated his commentary, written in 1412, to **Ulugh Beg**. Qāḍīzāde's commentary then became the subject of numerous supercommentaries by such authors as Sinān Pāshā (died: 1486) and **ʿAbd al-ʿAlī al-Birjandī**.

This continuous chain of astronomical learning represented by the *Mulakhkhaṣ* and its commentaries and supercommentaries – one that extended for a period of 500 years – is a significant indication of an active, ongoing educational tradition within Islam.

Sally P. Ragep

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Jai Singh II

Born **Amber, (Rajasthan, India), 3 November 1688**
Died **Jaipur, (Rajasthan, India), 2 October 1743**

Rājā Sawā'i Jai Singh II built the largest and fairly accurate masonry astronomical instruments ever constructed in India; he was also influential in introducing early modern European astronomical sciences to the Indian subcontinent. Sawā'i Jai Singh belonged to the Kachhwāha Rājpūt family, which ruled the state of Amber (located 7 miles northeast of the modern city of Jaipur). After the death of his father, Bhishan Singh, Sawā'i Jai Singh ascended the throne in 1700, when he was bestowed the title of Rājā by the then Mughal Emperor Aurangzeb (reigned: 1658–1707). Unofficially, the title *Sawā'i* was awarded when 8-year-old Jai Singh had the privilege of the first audience with Emperor Aurangzeb. He was officially proclaimed Sawā'i in 1713 at the start of the reign of emperor Farrukh Siyar (reigned: 1713–1719).

Following the Rājpūt family tradition, Sawā'i Jai Singh learned several languages during his youth: Sanskrit, Persian, Arabic, or Turkish, along with the Hindu scriptures (*Vedas* and other *Shāstras*) and also mathematics and astronomy. From an early age, he showed a keen interest and aptitude in astronomy. Two astronomical or astrological manuscripts were reportedly copied for Sawā'i Jai Singh when he was only 13 years old. According to another report during 1706/1707, the Rājā had 13 manuscripts concerning *Siddhāntic* astronomy copied for himself. His tutor, Samrāṭ **Jagannātha**, was a Marhaṭa Brahmin who was an expert in astronomical science (*Jyotiṣa*). It is therefore not surprising that Sawā'i Jai Singh developed his interest in astronomy and mathematics.

One of the Sanskrit manuscripts referred to above dealt with general astronomical instruments, while another with the title *Yantrarāja* explained the astrolabe. It was written *circa* 1380 by **Mahendra Sūrī** – a court astronomer of Sultan Fīrūz Shāh Tughalg (reigned: 1351–1388). It was therefore natural that Sawā'i Jai Singh's interest in observational astronomy led him to establish a number of astronomical observatories in five Indian cities, namely, Delhi, Jaipur, Banaras, Ujjain, and Mathura. These observatories are furnished even today with very large masonry instruments, many of which are various types of gnomons or shadow instruments. Before the construction of these large-scale instruments, Sawā'i Jai Singh first acquired or commissioned a number of portable instruments such as astrolabes, quadrants, column and ring dials, and so forth.

He also acquired noted Arabic and Persian books concerning theoretical and observational Islamic astronomy. As a sequel to these acquisitions, a tract, the *Yantraprakāra* (Mode of [Constructing Astronomical] instruments), was commissioned by Sawā'i Jai Singh. Historian of instruments S. R. Sarma has evaluated the importance of this work and argues that it "suggests the path of the evolution of the instruments designed by Jai Singh. The principle underlying several of these may have been known but to translate the principle into architecture, in such a majestic manner, as Jai Singh has done, is no mean achievement."

Sawā'i Jai Singh was reportedly commissioned by the Mughal Emperor Muḥammad Shāh to have a more modern *zīj* compiled by Mirzā Khayrullāh, since the *Zīj–i* of **Ulugh Beg** (the *ZUB*) was already 300 years old. Sawā'i Jai Singh realized that opportunity with the *Zīj–i Jadīd Muḥammad Shāhī (ZMS)*. In addition, he acquired and employed a number of Persian *zījes* as well as a few Arabic treatises on theoretical astronomy ('*Ilm al-Hay'a*), which he acknowledged in the preface to the *Zīj–i Muḥammad Shāhī* and dedicated it to Mughal emperor Muḥammad Shāh (reigned: 1719–1749).

Sawā'i Jai Singh wished to know more about Islamic astronomy and especially its theoretical models of planetary motion. As a result, he created a translation bureau of sorts and had standard Arabic and Persian astronomical manuscripts translated into Sanskrit. Sawā'i Jai Singh collected an impressive library of astronomical sources that was unrivalled in 18th-century India. The Library is extant even today in the palace of the present Maharaja of Jaipur.

Having met Father Emmanuel de Figueredo at Delhi or Agra (*circa* 1725–1727) and after briefings by him about developments in European astronomy, Sawā'i Jai Singh determined to send a delegation of Indian astronomers to the Portuguese King, headed by de Figueredo. The Indian delegation reached Portugal in January 1729 and returned in November 1730. Its members brought back a number of books, particularly copies of **Philippe de la Hire**'s

Astronomical Tables, and Johann Baptist Hömann's *Atlas Novus Coelestis* (Nürenberg 1725); the latter was important because it contained charts of the planetary systems of **Nicolaus Copernicus** and **Tycho Brahe** and also by **Giovanni Riccoli**. Sawā'i Jai Singh was likely briefed about these systems of planetary motion by his Jesuit collaborators. In turn, he invited a number of Jesuit cartographers and astronomers (*e.g.*, Claude Boudier) to Jaipur in order to discuss with them the discrepancies between the theoretical predictions and the actual observations of astronomical events.

Because the Jesuits were using small refracting telescopes to observe the satellites of Jupiter or occasional transits of Venus and Mercury, Sawā'i Jai Singh procured similar telescopes for his kingdom and used them to observe the crescent of Venus, satellites of Jupiter, the rings of Saturn, and sunspots. But for want of a micrometer device or cross-hair attachment, he could not conduct precise measurements with these telescopes.

The tradition of compiling *zīj*es in Persian was transmitted to India during the medieval period. We have already noted the transmission of the *ZUB* on which a commentary by an Indian, Mullāh Chānd, was written in the 16th century. The *ZMS* had been prepared in two stages or parts. Its first part contains sections on spherical astronomy and astronomical concepts in the traditional *zīj* style and was based solely on the *ZUB*. The second part was revised or freshly prepared after the aforementioned delegation returned from Portugal and was based on La Hire's *Tables*. It is a combination of literal translations coupled with adaptation of La Hire's *Tables* in the style of Persian *zīj*es. The *ZMS* became very popular not only in India but also in Iran and Central Asia, where it almost replaced the *ZUB*. Several commentaries were written on the *ZMS* in India, Iran, and Uzbekistan.

Sawā'i Jai Singh was probably disappointed with the compilation of the *ZMS*. Employing its tables of lunar motion, the observed values did not accurately match the theoretical predictions. Sawā'i Jai Singh wished to understand the geometrical model underlying the third lunar equation, and had no alternative but to have the relevant sections of La Hire's *Tables* translated literally into Sanskrit. The Rājā ordered his "astronomer royal" (*Jyotiṣarāja*), Kevalarāma, to translate La Hire's *Tables*. His composition, the *Dṛkpakṣasāraṇī (*Tables for Observational Astronomy*)*, was arranged in verse form and represents the first Sanskrit translation of La Hire's lunar theory. Yet, the most important prose translation was the tract, *Phiraṅgicandra-cchedyakopayogika* (Aid to Representation of the European Lunar Theory), which faithfully reproduced the heliocentric diagram of La Hire, along with the explanation that a planetary orbit was a Keplerian ellipse. The Sanskrit term used for "ellipse" is *matsyakara*, meaning "having shape of the fish." For these significant researches we are indebted to the late David Pingree.

Sawā'i Jai Singh succeeded in revitalizing and improving the knowledge of ancient and medieval Indian astronomy, by building a number of observatories so that the same phenomena could be observed from many locations – a unique instance in the whole of Asia during the medieval period. Moreover, by being receptive to astronomical ideas from different cultures, whether of Islamic or European origin, he demonstrated a "modern" scientific outlook, even in his premodern time. Yet, neither his sponsored Sanskrit translations of Islamic astronomical treatises, nor the translation of La Hire's lunar theory (with the heliocentric and Keplerian elements), became popular among the Sanskrit scholars of the Indian subcontinent.

S. M. Razaullah Ansari

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Jamāl al-Dīn

➜ **Zhamaluding: Jamāl al-Dīn Muḥammad ibn Ṭāhir ibn Muḥammad al-Zaydī al-Bukhārī**

Jansky, Karl Guthe

Born **Norman, Oklahoma, USA, 22 October 1905**
Died **Red Bank, New Jersey, USA, 14 February 1950**

Karl Jansky discovered extraterrestrial radio signals and tentatively identified their origin as the center of the Milky Way Galaxy. His discovery eventually revolutionized astronomy; Jansky can properly be thought of as the founder of radio astronomy.

Jansky's father, Cyril Methodius Jansky, was dean of the College of Engineering at the University of Oklahoma. Cyril Jansky had been born in Wisconsin of Czech immigrant parents who came to the United States in 1867. Karl's mother, Nellie (*née* Moreau), was of French–English descent. In 1908 the Jansky family moved from Oklahoma to Madison where Cyril Jansky became a member of the Electrical Engineering faculty at the University of Wisconsin. Karl graduated from the university with a BS in physics in 1927. He excelled scholastically (elected to Phi Beta Kappa) and in athletics he was the fastest skater on the university's ice-hockey team.

After a year of graduate study, for which he was awarded an MS in physics in 1936, Jansky joined the Bell Telephone Laboratories radio reception branch in 1928. His assignment was to study static and other radio interference. After some work at the long wavelength of 4,000 m, in March 1929 he began to design a rotating directional antenna system for observing static at about 15 m, a wavelength coming into use for transatlantic telephone service. Construction of the rotating antenna assembly began in the fall of 1929, and a year later the antenna and associated receiver-recorder were installed on a flat, open expanse of a fallow, southern New Jersey potato field near Holmdel, New Jersey. A bizarre contraption, reminiscent of the wing frame of an early Wright Brothers biplane, the antenna rotated silently around a circular track on four rubber-tired wheels from a Model-T Ford, completing on rotation every 20 min. Signals received by the antenna were connected to a radio receiver in a nearby shack, where they were amplified and recorded by pen on a moving paper chart. Jansky built the apparatus to investigate the direction of arrival of the crackling thunderstorm noise or "static" that interfered with conversations over transatlantic shortwave links of the Bell radio-telephone system.

In retrospect it is interesting to note that the system Jansky designed for studying 15-m wavelength static had:

(1) a directional antenna, likely the largest rotatable antenna in existence at the time;
(2) a receiver that was as quiet as the state of the art permitted, the noise level being limited by the electron noise of the vacuum tubes;
(3) a receiver responsive to a relatively wide band of wavelengths, much wider than in conventional receivers of the period; and
(4) an averaging arrangement, called a long time constant circuit, to smooth out the pen trace on the recorder chart, all characteristics essential to modern radio telescopes. Jansky was the first person to combine these four elements, and in so doing he built the first successful radio telescope.

In the late summer of 1931 Jansky started his antenna turning and his recorder running on a continuous basis. In addition to recording the signal on a chart, Jansky listened with earphones to the amplified radio receiver's output. Jansky found what he was looking for: Some static came from local thunderstorms, other static from more distant storms. The strength fluctuated greatly from hour to hour and day to day, but the main signals always came from the directions of storms.

But also in the earphones, Jansky heard a faint persistent static, so weak that he might have ignored it, for which the direction moved almost completely around the horizon once each day. Listening to the static with earphones, Jansky described it as a hissing sound "that can hardly be distinguished from the receiver noise." He had not anticipated the hiss-like static, but it excited his curiosity, and he determined to track it down. Jansky ruled out local interference from power lines or electrical equipment; in fact after further observations he concluded that the noise was coming from beyond the Earth. For some weeks the hiss-like static seemed to be strongest when the directional antenna was pointed toward the Sun. However, over a period of months the maximum moved away from the Sun, following a fixed point among the stars that Jansky eventually placed close to the center of our Galaxy.

By 1935, with tutoring from A. M. Skellett, a Bell Laboratories engineer who was also studying astronomy part-time at Princeton University, Jansky demonstrated that the hiss-like radiations were received any time his antenna was directed toward some part of our Galaxy, revealing its structure in a rudimentary way. The greatest response was obtained when the antenna pointed toward the center of the Galaxy. This fact led Jansky to the conclusion that the source of the radiation was located in the stars themselves or in the interstellar matter distributed throughout the Galaxy. Jansky noted that, if stars were the source, strong radiation should be observed from the Sun, whereas at no time had he detected any solar radio radiation. Unfortunately, Jansky made his observations during a sunspot minimum; had he continued his observations a few years more, he would undoubtedly have detected solar radiation during a period of high sunspot activity.

Jansky's conclusion that stars are not an important source of the galactic radiation was correct. He suggested that the hiss-like static "might [be] caused by the thermal agitation of charged particles which are found in the very considerable amount of interstellar matter that is distributed throughout the Milky Way." Jansky's suggestion turns out to be correct if the words "thermal agitation" are interpreted to include electrons moving at high velocity in a magnetic field. Jansky made one overt attempt to interest astronomers in his findings by publishing an article in *Popular Astronomy* in 1933.

Thus, by 1935 Jansky had identified the origin of the radio radiation with the structure of our Galaxy. He had detected the radiation at 15 m and also at 10 m, and he understood how this background radiation set a limit to useful receiver sensitivity. Jansky realized that progress in radio astronomy would require larger antennas with sharper beams that could be pointed easily in different directions. In fact, he proposed the construction of a parabolic-mirror antenna 30 meters in diameter for use at meter wavelengths. However, he obtained no support for his proposal, and radio astronomy languished. Unfortunately, Jansky was transferred to other research activities, and had no time or resources to pursue the subject further. Years were to pass before further advances were made in the still unrecognized new science of radio astronomy.

Jansky's discovery eventually revolutionized astronomy and our ideas of the Universe, but in the 1930s astronomers and engineers hardly raised an eyebrow. Jansky presented his final paper about his discovery on 3 July 1935, at the National Convention of the Institute of Radio Engineers in Detroit, Michigan. However, scarcely two dozen people were in the audience for this historic occasion, none of them astronomers. A few astronomers did take note of his work; for example, in 1934 **Harlan Stetson** included Jansky's discovery in his book on the interaction of the Earth with radio waves. Harvard astronomer **Fred Whipple** with his graduate student **Jesse Greenstein**, and others, hypothesized that the origin of the radiation that Jansky had detected would be associated with interstellar dust but showed that standard radiation processes were nowhere near powerful enough to account for the observations. Only Greenstein seemed convinced of the importance of the discovery.

Jansky died at the age of 44. He had developed Bright's disease (glomerulonephritis) at an early age, and his kidneys gradually failed. He had married Alice La Rue Knapp in 1929; they had two children.

Although **Grote Reber** and a few others made advances in radio astronomy prior to 1950, there was nothing at the time to hint of the great leaps that would soon follow. Regrettably, Karl Jansky did not live to witness the tremendous astronomical revolution that resulted from his discovery. However, his name is commemorated in radio astronomy. The jansky is a unit of flux density or strength of radiation, putting him in the illustrious company of other electrical pioneers for whom the watt, ampère, volt, ohm, coulomb, hertz, and farad are named.

John Kraus

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Janssen, Pierre Jules César

Born **Paris, France, 22 February 1824**
Died **Meudon near Paris, France, 23 December 1907**

French solar astronomer Jules Janssen discovered that it is possible to see prominences beyond the limb of the Sun without waiting for an eclipse, demonstrated that some features in the solar spectrum are actually caused by gases in the Earth's atmosphere, and reported erroneously a large quantity of water vapour in the atmosphere of Mars, which gave support to the then-popular idea of an inhabited planet.

A childhood accident left Janssen permanently lame, and he was educated at home. He initially started work in a bank and took up formal education only at the university level as an adult. He received his *licence ès sciences* at the Sorbonne in 1852 and then worked as a calculator at the Paris Observatory. Indeed, Janssen was dependent on a series of temporary jobs and stipends until 1865, when he was appointed to the chair of physics at the École Speciale d'Architecture in Paris.

Despite his handicap, Janssen was an inveterate astronomical traveler. Indeed, at the age of 66 he devised a carrying chair that, borne by porters, allowed him to continue observing the Sun from Mont Blanc. His first expedition was to Peru in 1856, to determine the location of the magnetic Equator, and most of the later ones were for solar observation, often during eclipses. The most often told story is of his escape from Bismarck's siege of Paris in 1870 (during the Franco–Prussian War) when he and his equipment left by balloon. Janssen reached Oran, Algeria, in time for the eclipse, but was clouded out.

Scientifically, the most important of Janssen's eclipse observations came in India in 1868, when the extreme brightness of the emission lines from the prominences on the solar limb persuaded him that they ought to be visible outside of eclipse as well, if the scattered continuum light was sufficiently diluted by wavelength resolution. This proved to be the case, and he was even able to image prominence structure by opening up the slit of his spectrograph. **Norman Lockyer** had the same inspiration and made the same discovery 2 months later, and the two are jointly credited. They were also joint discoverers of a yellow emission line close to, but different from, the sodium D feature. (It comes from helium, and another 30 years passed before the line was seen in laboratory spectra of gas escaping radioactive materials.)

Janssen's Ph.D., defended in 1860, was on absorption of radiation in the human eye, and, though he quickly deviated from ophthalmology and medicine, he retained a lifelong interest in optical instrumentation. He set up a small observatory outside of Paris in 1862 near his home and developed a high-dispersion spectrograph using compound prisms, of importance in his later work. With it he established, by observing from different altitudes and different locations with varying humidity, that certain broad bands of absorption in the solar spectrum are actually due to the Earth's atmosphere. Janssen accordingly called these "telluric bands," and was able to show that the main absorber is water vapor. He seems to have had a special fondness for volcanic sites, specially Vesuvius, Santorini, and Kilauea. The definitive indication was made in 1866 at the site of a gas factory, where swamp gas was partially purified to methane, shooting steam into the air.

Janssen's fondness for water features, however, led him astray: In 1867, he reported the detection of copious quantities of water vapor in the spectrum of Mars. This fit well with contemporary enthusiasm for canals and vegetation on Mars. Curiously, his results were "confirmed" by **William Huggins** and **Hermann Vogel**, but work by **William Campbell** in 1894 and 1909 set a much lower limit to the amount of water in the Martian air. Indeed, it actually was seen only in 1963/1964 by L. D. Kaplan, G. Münch, and H. Spinrad. Janssen was, however, completely correct in pointing out in 1879 that the then still popular idea of an inhabited Sun was ridiculous.

Janssen's device for imaging solar prominences was a prototype of the spectrohelioscope. It was left to **George Hale** to add photographic plates to produce the first spectroheliograph, but Janssen invented other photographic devices, including an "astronomical revolver," permitting many short images to be taken in quick succession. He used this to get measurements of the position of Venus moving across the solar limb during the 1874 transit, and his work counts both as pioneering photographic astrometry and as a remote ancestor of the motion picture.

The French government agreed to Janssen's choice of Meudon (an old royal domain that otherwise would have been divided up for housing) as a site for a new solar observatory in 1874. The complement of instruments was not completed until 1893, but Janssen began a regular series of solar photographs from there in 1876, continuing until 1903, when he compiled an atlas of the best 6,000 images. It was widely used for synoptic studies of the Sun (activity, rotation, and so forth), and the quality of the images, which resolved granulation as fine as 1″, was not bettered until the 1950s.

In addition, Janssen was one of the first to propose observation from a balloon above a clouded site, in particular for the Leonid meteor shower of 1898. He was the founder of the *Annales de l'Observatoire d'astronomie physique de Paris*.

His honors included membership in the Academy of Sciences, Paris (1873), membership in the Bureau des longitudes (1874), and a foreign associateship in the Royal Astronomical Society (1872). Janssen died only 7 months after serving as the president of the Solar Congress held at Meudon.

Raymonde Barthalot

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Jarry-Desloges, René

Born **Remilly's Castler, Ardennes, France, 1 February 1868**
Died **Cannes, France, 1 June 1951**

Réne Jarry-Desloges conducted an extended study of the impact of geography and atmospheric conditions on astronomical observation while carrying out an intense program of planetary observation at different observatories. He used his appreciable assets to build six separate observatories on two continents and made them available to colleagues and conducted his own observation, publishing the results in a journal that is a classic source for visual observations of planets.

Jarry-Desloges's father, independently wealthy with an unearned income, provided his son René with advantages enjoyed by only a few other amateur astronomers, most notably **Percival Lowell**. Jarry-Desloges enrolled in the French Astronomical Society [SAF] in 1889, just 2 years after it was founded by **Camille Flammarion** in 1887. Finding himself the owner of a small fortune, Jarry-Desloges devoted most of his time to astronomy. He decided to follow the way paved by Lowell and initiated studies of the planets and of the Moon.

By 1907, Jarry-Desloges had progressed to the point of understanding how important local seeing conditions were for satisfactory lunar and planetary observing. He published a relevant article entitled "Searching for a better atmosphere for astronomical observations." In the same year he opened what proved to be a temporary observatory on Mont Revard in Savoie. The Mont Revard Observatory, at an altitude of 1,550 m, was at the highest elevation of any of the six observatories Jarry-Desloges ultimately opened. His investment provides some evidence of the seriousness with which he approached the problem in that the facilities at Mont Revard included a 29-cm Merz refractor mounted equatorially in a 5-m dome. By 1909, he had become dissatisfied with the atmospheric conditions on Mont Rivard and opened two additional observatory sites. One was located at Le Masseqros, Lozère at 900 m elevation, and equipped with a 37-cm refractor made by Emile Schaer (1862–1931) of Switzerland. This observatory remained in operation until 1912, when both Le Masseqros and Mont Revard were closed. The second observatory, opened in 1909 near sea level at Toury, Eure-et-Loir, was closed after only a year.

By the winter of 1911 it is clear that Jarry-Desloges was again dissatisfied with observing conditions at his observatories, for in that year he made his first trip to North Africa, visiting sites near Oran, Morocco, and at Batna and Sétif, Algeria. The Moroccan site was eliminated because of excessive temperature variations caused by its proximity to the cold waters of the Atlantic. Similar problems at Batna, coupled with excessive dust blowing off the Sahara desert, eliminated that site even though it had more beautifully clear nights per year than Setif. A site at Laghouat, Algeria, at an elevation of 735 m, was also evaluated in the period 1913/1914. During this period, Jarry-Desloges also apparently entered into discussions with Lowell on founding a jointly owned observing station in the Atacama Desert in Chile. That venture collapsed when Lowell suddenly died in 1916. An observatory was opened briefly in 1929 at Chelles, in Seine-et-Marine, but was closed when it was discovered that the site was an important prehistoric settlement and had considerable archaeological significance.

For the site at Setif, at an elevation of 735 m, Jarry-Desloges built a 7-m dome and installed a 50-cm refractor by Schaer, though this instrument may ultimately have been found less than fully satisfactory for planetary work. A Merz 26-cm apochromatic refractor was mounted in parallel with the 50-cm Schaer. Georges Fournier speculated that Jarry-Desloges's intent was to compare the effect of seeing on the two apertures differing by a factor 2, but also to make an appraisal of whether the larger aperture was more important than the finer optical quality of the smaller instrument. Later, the 37-cm Schaer refractor was relocated to Setif and became the primary instrument in use there. The site at Setif was made permanent in 1924 when a home for observers was constructed near the dome. Not content with the operation of his own observatories, Jarry-Desloges sometimes used the telescope of the east tower of the Paris Observatory, with the permission of observatory director **Camille Bigourdan**, and the 83-cm refractor of the Meudon Observatory at the invitation of **Henri Deslandres**.

To assist him in carrying out observations at these multiple observatories, Jarry-Desloges periodically employed other observers. In addition to Georges Fournier, a well-known planetary observer who had previously observed with Flammarion at the Juvisy Observatory, Jarry-Desloges employed V. Fournier from 1909 to 1914, P. Briault from 1915 to 1918, and M. Hudelot in 1924. Georges Fournier was apparently employed at the Jarry-Desloges observatories from 1909 until Jarrry-Desloges finally closed down the operation sometime after 1947. In his reporting of observations, Jarry-Desloges always combined the results of his observatories, giving full credit to the observers involved at each location.

It will be seen, then, that Jarry-Desloges actively engaged the problems of planetary observation. His main efforts were directed toward Mars, but the other planets were not neglected. For example, he observed Mercury sufficiently to agree, as did many other observers including Lowell and **Eugène Antoniadi**, with the erroneous 88-day period of rotation first announced by **Giovanni Schiaparelli**.

The observation of planets and of the Moon by Jarry-Desloges and his staff from 1907 to 1941 was published at his expense in 10 volumes of 250 to 300 pages each, the equivalent of the work worthy of a professional observer and observatory. Those volumes contain numerous illustrated plates, mostly drawings of Mars but also of Mercury, Venus, Jupiter, Saturn, Uranus, and the Moon. The French Academy of Science awarded Jarry-Desloges their Janssen Gold Medal in 1914 and then the Guzman Prize. In 1921, the SAF also awarded him their Janssen Prize. Jarry-Desloges served as president of the International Astronomical Union Commission dedicated to the physical study of planets.

Patrick Fuentes

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Javelle, Stéphane

Born: **Lyon, France, 16 November 1864**
Died **Nice, France, 3 August 1917**

During his 33 years as an astronomer at the Nice Observatory, Stéphane Javelle discovered nearly 2,000 nebulae and recovered six periodic comets. Javelle took an active part in the measurement of the speed of light as well as in the Eros solar parallax campaign undertaken by **Henri Perrotin**, the first director of the Nice Observatory.

In 1883 Javelle took his baccalaureate in Lyon, where his father manufactured furniture and his mother was a seamstress. Javelle was employed as an accountant by a Lyon industrialist who happened to be a friend of the astronomer **Louis Thollon**. At the time Thollon had just finished the construction of a large spectroscope with which he planned to study the Sun's spectrum at the Nice Observatory, a private institution owned by financier Raphaël Louis Bischoffsheim. Thollon recommended Javelle to Perrotin, who employed him at the Nice Observatory as a "student" astronomer in 1884. Javelle began by assisting Perrotin with his double-star observations and Thollon in his investigation of the solar spectrum. After he learned how to use the instruments and to make astronomical observations, in 1889 Perrotin assigned Javelle responsibility for the 76-cm refractor at Mont-Gros. For the next 28 years, Javelle was the main observer on this powerful but somewhat impractical instrument. Installed in 1887, this telescope was, for a short time, the largest refractor in the world.

Javelle's initial projects involved visual observations of comets and asteroids. However, as early as 1890 he began to specialize in searching for faint nebulae. In December 1894 Javelle was awarded the Lalande Prize by the French Academy of Sciences for his discovery and measurement of the positions of 1,100 previously uncataloged faint nebulae. His first catalog, published in 1895 in Volume IV of the *Annales de l'Observatoire de Nice*, contained 505 recently discovered nebulae, while his second, published in 1897 in Volume VI, contained 302 nebulae. The micrometric positions of these 807 nebulae, reduced to 1860.0, were based on comparison stars from the Bonn Catalogue. A third catalog, containing 662 nebulae that Javelle had discovered and measured up to 1903, was published in 1908 in Volume XI of the *Annales*. Over half of the objects listed in **John Dreyer**'s *Index Catalogue* (1895) were credited to Javelle, while 17% of the objects in Dreyer's *Second Index Catalogue* (1910) were also Javelle's discoveries.

When Javelle was awarded the Valz Prize by the French Academy of Sciences in December 1910, the publication of his fourth catalog was said to be "well advanced." By 1912, Javelle had finished his next catalog, which brought the number of nebulae discovered and measured by him to a total of 1,869. However, it was only printed as a preliminary monograph, as had been the case for each of his first three catalogs; the fourth catalog never appeared formally in the *Annales*.

In 1899, Bischoffsheim deeded the Nice Observatory in his will to La Sorbonne, Paris, and transferred scientific control of the observatory's program to the *savants* in Paris. From 1899 onward Javelle carried out many other assigned tasks that reduced his available time for searching for faint nebulae. He observed comets, especially faint ones; he successfully searched for the return of periodic comets and followed those moving away from the Sun as long as possible. For example, in 1910 he followed comet 1P/Halley until the end of November. Javelle reported these observations in the *Comptes rendus de l'Académie des sciences*, both as the sole author and with his colleague Michel Giacobini (1873–1938) who was employed at the Nice Observatory from 1888 until 1909. Javelle also took part in the experimental determination of the speed of light carried out between 1898 and 1902 by Perrotin and Maurice Prim (1863–1937) at the request of the Sorbonne physicist **Alfred Cornu**. However, Javelle's name never appeared in the publications reporting this work.

In 1900 and 1901, Nice Observatory contributed to the international determination of the solar parallax by observing (433) Eros, the first minor planet discovered with an orbit that passes close to the Earth. The observations, which included those carried out by Javelle and Perrotin with the 76-cm refractor, were published in 1908 in Volume XI of the *Annales*. Two years later Javelle published in Volume XII the observations he had made of comets and asteroids with the same instrument between 1892 and 1900.

When Javelle was awarded the Valz Prize, the citation mentioned his observations of nearly 600 comets and small planets, his work on Eros, and his participation in the solar eclipse expedition of 1905 to Alcala de Chisvert in Spain, together with his uninterrupted 20 years of systematic search for faint nebula. However, even this official recognition did not prevent his situation from deteriorating. Around 1912 he was asked to reduce his work on nebulae and to devote more time to the observation of asteroids as part of a collaboration between Nice, Vienna, and Heidelberg.

At the outbreak of World War I, most of the Mont-Gros staff were mobilized so that by the beginning of 1915 Javelle, aged 50, was the only remaining astronomer who did any observing at Nice. Until his death Javelle was officially in charge of the observatory library. He also did secretarial work, which, for many years, included observatory accounting. Thus, it appears that pension difficulties he experienced may have been related to his civil-service classification in an administrative category rather than as a scientist, a question that might be resolved by further investigation in civil records. Javelle's death was announced in *The Observatory*; it does not appear to have been reported in any French journal, perhaps because of the continued hostilities of World War I.

Françoise le Guet Tully

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Jawharī: al-ʿAbbās ibn Saʿīd al-Jawharī

Flourished **Baghdad, (Iraq), 830**

Jawharī made solar, lunar, and planetary observations in Baghdad from 829 to 830, the data of which appeared in the astronomical handbook with tables that is sometimes referred to as *Kitāb al-Zīj*. Most likely, this is a reference to the *Mumtaḥan zīj,* which was apparently jointly authored by several astronomers at the court of the ʿAbbāsid caliph **Ma'mūn**. Charged by the caliph with the task of providing appropriate instruments for the year-long series of astronomical observations at Damascus in 832–833, Jawharī selected **Khālid ibn ʿAbd al-Malik al-Marwarrūdhī** to construct them. Jawharī also contributed to the accuracy of the calculated solar and lunar data; these results also appeared in the *Mumtaḥan zīj*. His astronomical writings were later consulted by **Shams al-Dīn al-Samarqandī**, a contemporary of **Naṣīr al-Dīn al-Ṭūsī**. In his work on the parallels postulate of Euclid, Ṭūsī noted the failure of Jawharī to prove the parallels postulate in the latter's commentary on Euclid's *Elements*; this treatise of Jawharī survives only in fragmentary references.

Marvin Bolt

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Jean de Meurs

John of [Johannes de] Muris [Murs]

Jeans, James Hopwood

Born **Ormskirk, Lancashire, England, 22 September 1877**
Died **Dorking, Surrey, England, 16 September 1946**

British mathematician and astronomer James Jeans formulated two astrophysical concepts: the Jeans mass or Jeans length for deciding whether a given mass of gas will collapse under its own gravitational force and the Rayleigh–Jeans approximation to the long-wavelength part of blackbody radiation. For much of his life he supported the Chamberlin–Moulton or tidal encounter hypothesis for the formation of the Solar System and favored a very long timescale, perhaps 10^{12} years, for the Universe as a whole.

Jeans, whose mother was a Hopwood, was the son of William Tulloch Jeans, a parliamentary journalist. He was educated at Trinity College, Cambridge, in 1896. He tied for the second best score (second wrangler) in part I of the mathematics *tripos* in 1898. Jeans took a first-class honors degree in Part II in 1900. He was awarded an Isaac Newton Studentship and the Smith's Prize in 1900, the latter for an essay on thermodynamics and statistical mechanics of gasses.

Jeans was elected a fellow of Trinity College in 1901 and appointed a lecturer in mathematics in 1904. Seeing no immediate opportunity for further advancement he accepted a professorship in applied mathematics at Princeton University in 1905, returning to Cambridge as Stokes Lecturer in 1910. While at Princeton, Jeans married Charlotte Mitchell of Vermont who died in 1934, leaving one daughter. In 1935, he married Suzanne (Susi) Hock of Vienna, Austria, who survived him along with their three children.

Jeans experienced intermittent bouts of tuberculosis and heart problems through much of his adult life. He resigned the Cambridge lectureship in 1912, and held only more or less honorary positions thereafter (a Royal Institution professorship 1935–1946 and a research associateship at Mount Wilson Observatory 1923–1946).

Jeans's early work at Cambridge was carried out under **George Darwin**, who pioneered some of the mathematical methods that Jeans later applied to the behavior, first, of large assemblages of molecules, and, second, of large assemblages of stars. A few examples must suffice. His analysis of the stability of rotating fluid masses showed that if binary stars form from single rotating gas clouds, they must do so *via* violent fragmentation and not *via* quasi-static fission, because the more distorted configurations are more unstable. Starting in about 1900, Jeans reconsidered the question of radiation from gas in equilibrium at a given temperature, previously addressed by Lord Rayleigh, and concluded that the flux should increase monotonically to shorter wavelengths, no matter what the temperature of the gas. This is manifestly wrong, and the Rayleigh–Jeans law (though a good approximation to radio emission from ionized interstellar clouds) served to show that something was drastically wrong with classical considerations of gas and radiation. The correct expression was put forward by **Max Planck** at about the same time and was an early example of quantization of energy.

Jeans also examined the expected dynamical evolution of binary systems and of clusters and whole galaxies of stars. He concluded that to reach the current conditions (binaries with eccentric orbits and relaxed clusters and galaxies) would have required 10^{12} years, using the dynamical processes and initial conditions that he thought appropriate. Jeans was, therefore, driven to suppose that stars derive their energy from annihilation of matter, so that they can live that long, rather than from the "subatomic processes" advocated by **Arthur Eddington**.

His calculations for rotating fluids also persuaded Jeans that the Solar System could not have formed from a single, rotating gas cloud, or the Sun would be a very rapid rotator and have most of the angular momentum in the system. He therefore endorsed and provided a more detailed calculation of the tidal encounter (Chamberlin–Moulton) hypothesis, which said that the planets were made of material dragged out of the Sun by a close passage of another star. Such close approaches must be very rare (a calculation which he did correctly), and so planetary systems must be very rare. Jeans changed his mind on the age of the Universe and the likelihood of other planets only very near the end of his life.

The book *Astronomy and Cosmogony* (one of more than half a dozen that he wrote primarily for the educated public) contains a suggestion that new matter is pouring into our Universe from some other dimension at the centers of spiral galaxies. **Fred Hoyle** credited him as the inventor of the idea of continuous creation in his own 1948 paper on steady-state cosmology.

Jeans received a very large number of honorary doctorates, medals, and other honors from organizations in Britain, the United States, and India. He was knighted in 1928 and received the higher honor of the Order of Merit (both for his original scientific contributions and for his communicating science to the public) in 1937. Jeans was president of the Royal Astronomical Society in 1925–1927 and established its George Darwin lectureship by providing the initial endowment. He was elected to the Royal Society in 1906 and served as one of its secretaries from 1919 to 1929, during which time he developed part A (mathematics and physical sciences) of its *Proceedings* into a leading scientific journal.

Jeans was an enthusiastic amateur musician. He was the author of a book on the physics of music who installed a large pipe organ in his retirement home, which he shared with his second wife, some of whose playing was preserved in recordings archived by the Royal Astronomical Society.

David Jefferies

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Jeaurat, Edme-Sébastien

Born **Paris, France, 14 September 1724**
Died **Paris, France, 8 March 1803**

Edme Jeaurat was an observational astronomer and an editor of the *Connaissance des temps*. He was the son of an engraver of the king, his mother the daughter of Sébastien Leclerc. Etienne Jeaurat, his uncle, who would become a painter for the queen, taught Jeaurat to draw. A friend of the family, Lieutaud, astronomer of the Académie des sciences, taught him mathematics. Thanks to his artistic training, Jeaurat received a medal from the Academy of Painting at the age of 22 and, in 1750, published an "Essai de perspective à l'usage des artistes."

But Jeaurat was now more interested in mathematics than in drawing. In 1749, as a geographer-engineer, he worked on the *Carte de France* project under the direction of **César Cassini de Thury**. In 1753 he was appointed teacher of mathematics at the Military School, then in a temporary establishment at Vincennes. There he met **Joseph–Jérôme Lalande**, who steered him to astronomy.

Jeaurat's first observation was that of comet 1P/Halley. In 1760 he founded the first observatory of the Military School recently established at the Champ de Mars, Paris. It was a wooden building, rather fragile above a mansarde, where he had several instruments, including a heliometer with an 18-ft focus, with which he observed the oppositions of Jupiter and Saturn. In 1763, Jeaurat and **Jean Bailly** were in competition to enter the Académie des sciences, but both were named, Jeaurat as a supernumerary astronomer, then geometer, and Bailly as an astronomer. Jeaurat later became an associate and finally a pensioner in 1785.

In 1766 Jeaurat published new tables of Jupiter along with Bailly's theory on satellites. A second observatory with one story was built for him at the Military School; it had a small platform and a round room with a roll-off roof. Jeaurat moved his instruments there in May 1769 and observed the transit of Venus on 3 June 1769. The following year he left this observatory and moved into lodgings at the Royal Observatory, vacant since **Jean Chappe d'Auteroche** died in California (Mexico). There he made a few observations of the planets and eclipses until 1787.

In 1772, Lalande, having been become a pensioner of the academy, resigned as editor of the *Connaissance des temps*. Jeaurat succeeded him and continued the changes inaugurated by his predecessor in 1760. Jeaurat published 12 volumes, covering the years from 1776 to 1787, including data such as **Tobias Mayer**'s zodiacal catalog, **James Bradley**'s observations, the positions of Parisian steeples, and **Charles Messier**'s great catalog of nebulae. When Jeaurat himself became a pensioner, he handed the editorial duties to **Pierre Méchain**. During this period Jeaurat published a few works on optical instruments: for example, he described in 1778 a refracting telescope with a double image, later fabricated by the optician Navarre. When the rebuilding of the vaults of the Paris Observatory began in 1787, Jeaurat had to leave. He became assistant director, then director, of the academy in 1791/1792. With the suppression of the academies during the Revolution (1793), he lost his pension and his savings. In 1794, Jeaurat wrote on behalf of his observatory colleagues to defend their good citizenship. He was elected to the astronomy section of the Institut de France in December 1796, after the death of **Alexandre Pingré**. Jeaurat then moved back to the observatory and was allowed to remain there, by the Bureau des longitudes, until his death.

Simone Dumont

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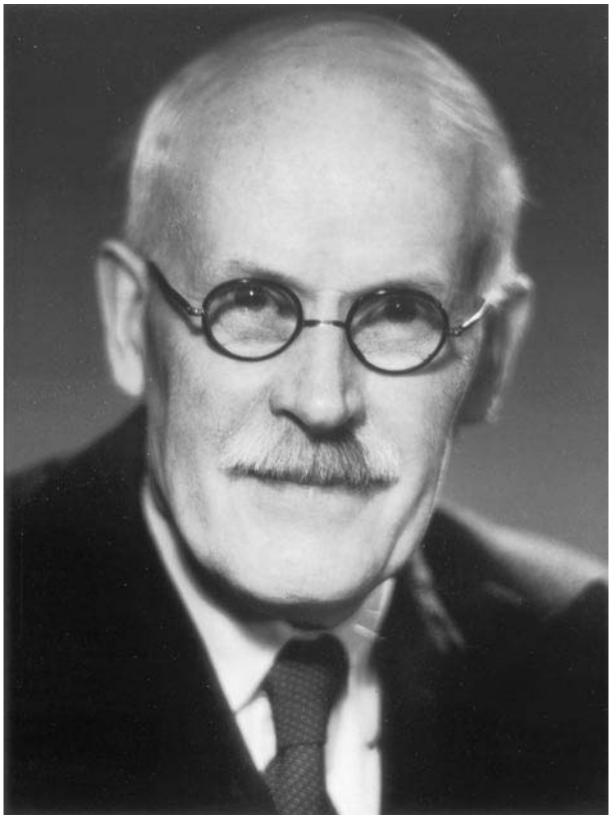
Jeffreys, Harold

Born **Fatfield, Durham, England, 22 April 1891**
Died **Cambridge, England, 18 March 1989**

Geoscientist Harold Jeffreys is most happily remembered today as the J of the WKB-J (Wentzel–Kramers–Brillouin) method for obtaining solutions of certain classes of differential equations of great importance in quantum mechanics and other branches of modern physics. He is less happily remembered as one of the last opponents of the concept of mantle convection, plate tectonics, and continental drift, the best current understanding of the evolution and behavior of the Earth's outer layers.



Jeffreys had a head start in his early education as he was born in the village school of Fatfield where his father, Robert Hall, was headmaster and his mother, Elizabeth Mary Sharpe, was a teacher. As a teenager Harold had interests in photography and botany. In 1907 he went to Armstrong College in Newcastle upon Tyne, then a part of the University of Durham, which is now the University of Newcastle upon Tyne. He graduated from there with distinction in mathematics, and, in 1910, was admitted to Saint John's College, Cambridge. There he earned bachelor's and master's degrees and was elected a fellow in 1914. The association would last a lifetime.

An essay on nutation and precession, topics Jeffreys would return to, won him the Adams Memorial Prize at Saint John's College in 1912. Thus, at the start of his career he was showing an interest in research in the field of dynamical astronomy. A particular interest would be the theory of tidal evolution of the Solar System.

The period from 1915 to 1917 found Jeffreys working in Cambridge's famous Cavendish Laboratory on war-related projects that led him to study fluid dynamics. In 1917 he was awarded a D.Sc. from Durham. Over the next 5 years Jeffreys was engaged by the Meteorological Office where he studied atmospheric circulation including the roles of cyclones.

From 1922 to 1931 Jeffreys served as a fellow and lecturer at Saint John's College. He was appointed University Reader in Geophysics in 1931 and remained in that position for 15 years, until elected Plumian Professor of Astronomy and Experimental Physics, a position he held until his retirement in 1958.

During his life, Jeffreys worked in and made significant contributions to a number of interrelated areas: hydrodynamics, celestial mechanics, seismology (especially the physics of the Earth's interior), probability, and pure mathematics. He was also one of the first to explore the influence of radioactivity on the Earth's cooling.

Seismology was Jeffreys' lifelong passion. Of particular interest to him was how earthquake waves could aid in investigating the interior of the Earth. In 1921 he deduced from seismic records associated with an explosion in the Rhineland that the Earth's crust has at least two layers above the mantle. Some 6 years later, he demonstrated that the Earth must have a dense, liquid core, a result that has been amply confirmed subsequently. His third major discovery was the division between the upper and lower mantle that he attributed to a change in the crystal structure of olivine.

Jeffreys spent many years on calculations of the travel times of seismic waves through the Earth. (His calculator is on display at Cambridge University's library.) These data would not only provide more precise locations of remote earthquake sources, but also allow a better understanding of seismic-velocity structure within the Earth's interior. The work was started in 1931, and he was joined by K. E. Bullen as a research student. By the end of the decade the Jeffreys–Bullen tables were published, and a reliable velocity model for the Earth was complete.

Jeffreys wrote extensively on the dynamics of the Earth and the Solar System using materials derived from his own studies and those of graduate students. Among his investigations was a study of the variations in the rotation of the Earth including the effects of a liquid core. In particular, he showed that slowing down of the Earth's rotation, derived from astronomical observations, was most likely due to eddy viscosity in shallow seas. Subsequently, this result has been largely confirmed.

Jeffreys' book *The Earth: Its Origin, History and Physical Constitution*, first published in 1924, presented the first systematic account of the physical state of the Earth as a whole and influenced the study of geophysics for many years as it went through successive editions. However, it was not without controversy. In latter editions, Jeffreys continued to oppose the ideas of mantle convection, continental drift, and plate tectonics, which were generally accepted after about 1965.

Most of Jeffreys' significant work in geophysics was completed before the advent of such new research tools as artificial satellites or deep drillings in the ocean floors. But often his results were the basis for later developments. Jeffreys' work on the theory of the Earth's gravitational field, as an example, showed gravity highs over the North Atlantic and the Pacific, and gravity lows over the Caribbean and Indian Ocean. These results were met with skepticism but subsequently vindicated by data obtained from the perturbations of artificial-satellite orbits.

Again, as a pioneer in planetology, Jeffreys argued in 1923 that Uranus and Neptune would have surface temperatures (controlled mainly by the Sun's radiation) of about −120 °C. This view was contrary to the generally accepted beliefs at the time but proved correct, as did his suggestion that the densities of these two planets indicated that their primary constituents must have molecular weights similar to methane and ammonia.

Jeffrey's *The Theory of Probability,* first published in 1939, was based on Bayesian methods that were not then popular but that are now widespread in such areas as risk assessment and astronomy.

Throughout his long career, Jeffreys played an instrumental role in many organizations: He was elected a fellow of the Royal Society in 1925, he was president of the Royal Astronomical Society from 1955 to 1957, and he served on the council for over three separate periods: 1919–1928, 1929–1931, 1955–1960. From 1946 to 1957 Jeffreys was honorary director of the International Seismological Summary; in 1964 he served as president of the International Association of Seismology of the Earth's Interior.

Jeffreys won many awards including the Gold Medal of the Royal Astronomical Society (1937), the medal of the Royal Society of London (1948), the Bakerian Lecturer of the Royal Society (1952), the Bowie Medal of the American Geophysical Union (1952), the Royal Society's Copley Medal (1960), Columbia University's Vethesen Prize (1962), the Royal Statistical Society's Guy Medal (1963), the medal of the Seismological Society of America (1978), and the Wollaston Medal of the Geographical Society. He was a recipient of the Victoria Medal of the Royal Geographic Society and was awarded honorary degrees by the universities of Liverpool and Dublin. Moreover, he was made a Knight Bachelor in 1953.

During 1940, Jeffreys married Bertha Swirles. They had no children. Lady Jeffreys was a mathematician and vice mistress of Girton College, Cambridge, from 1966 to 1969. With him, she coauthored *Methods of Mathematical Physics* (1946), which incorporated much of his original work in mathematics including studies of operational methods for the solution of differential equations and asymptotic methods. She survived him by a decade.

Following the end of World War II, Jeffreys traveled extensively, spending 5 months at Columbia University's Lamont Geological Observatory and a similar period of time at Southern Methodist University. In addition to his research he lectured on a range of topics in mathematics, statistics, and geophysics to both students and research groups.

According to those who knew him, Sir Harold Jeffreys was somewhat over medium height and usually dressed informally. Although very difficult to talk to, he was sociable and dined regularly at Saint John's College. For many years he sang tenor in the Cambridge Philharmonic Choir. He had wide interests both in science and beyond. His writings include papers on physics and psychology; he was also an expert photographer.

George S. Mumford

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Jehan de Murs

➔ **John of [Johannes de] Muris [Murs]**

Jenkins, Louise Freeland

Born **Fitchburg, Massachusetts, USA, 5 July 1888**
Died **New Haven, Connecticut, USA, 9 May 1970**

American astrometrist Louise Jenkins compiled a valuable catalog of stars within 10 parsecs of the Sun and edited the third edition of the *Yale Bright Star Catalogue*. Only 12 of the nearby stars are brighter than $V = 6.5$.

Jenkins attended Mount Holyoke College where she studied under professor **Anne Young**, earning her AB in 1911 and MA in 1917. Meanwhile, she was appointed as assistant in astronomy at Mount Holyoke, 1911–1913, computer at Allegheny Observatory, 1913–1915 (where **Frank Schlesinger** was then director), and instructor at Mount Holyoke, 1915–1920. From 1917 to 1920 Jenkins observed sunspots at the Mount Holyoke telescope, reporting her observations in *Popular Astronomy*. In 1919 she joined the American Association of Variable Star Observers [AAVSO]. With Young in 1920, Jenkins determined the proper motions of some 34 variable stars.

From 1920 to 1932 Jenkins was a member of the Women's American Baptist for Missionaries Society. In 1920 she went as missionary to Japan, where she taught English and Bible at the Women's Christian College. Before she left for Japan, AAVSO member Charles Elmer (of Perkin–Elmer Corporation, telescope makers) loaned her a 3-in. telescope that she used for educating the students under her care, as well as for observing variable stars. Jenkins is reputed to have been the first woman to observe variable stars from Japan, making 164 observations reported to the AAVSO in 1921–1923. Unfortunately, she experienced the Japanese earthquake of 1923, in which the telescope was destroyed. Jenkins organized an amateur astronomy club in Japan and arranged for the members to visit the Tokyo Observatory once a month. In 1925 she returned to the United States after her father died, but went back to Japan to teach at a girls' high school and other schools (1926–1932). Jenkins enjoyed teaching and was well liked by her students.

Upon again returning to the United States, Jenkins was employed at the Yale Observatory by director Frank Schlesinger who remembered her good work at Allegheny Observatory. She was an assistant (1932–1938), secretary of the department (1938–1947), and assistant editor of the *Astronomical Journal* (1942–1958). Jenkins played a significant role in the determination of stellar parallaxes and in the compilation of numerous catalogs, coauthoring with Schlesinger, the second edition of the *Yale Catalogue of Bright Stars* in 1940, and the second edition of the General Catalogue of Stellar Parallaxes in 1935. The third edition of the latter (in 1952 with supplement in 1963) was compiled entirely by Jenkins. Schlesinger's first publication of parallaxes determined under his direction at Yale, The Trigonometric Parallaxes of 851 Stars (1936), contained 41 parallaxes determined by Jenkins, who is also credited with the preparation for the press of the entire 232-page compilation from 10 participants. In all, through 1962, over 350 parallaxes were determined by Jenkins or under her direction for stars photographed at Yale's southern station in Johannesburg, South Africa. She also made a valuable compilation in 1938 of 127 stars whose parallaxes indicated that they are within 10 parsecs of the Sun; of these, 48 are bright stars (6.5 V or brighter).

In 1957 Jenkins paid her final visit to Japan, attending missionary meetings in Tokyo and Karuizawa. On 3 October 1957, she visited the Tokyo Astronomical Observatory a day before the launching of the first Soviet artificial satellite. Then, at the International Christian University, Jenkins happened to fall and break a leg, precluding other planned visits. Hospitalized for a full month and still in a wheel chair, she decided to fly back home.

Before long, Jenkins was back at Yale doing volunteer work in her favorite field, the determination of stellar parallaxes, through 1968. She died in a retirement home, having kept up correspondence with her Japanese colleagues and friends through January 1970.

Dorrit Hoffleit

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Jia Kui

Flourished **Xianyang, (Shaanxi), China, 30–101**

Jia Kui, a Chinese astronomer of the Later Han dynasty (25–220), improved Chinese understanding of the Moon's motions and detected the precession of the equinoxes, improving Chinese calendars in the process. In the year 85, a group of astronomers including Jia Kui was put in charge of improving the *Sifen* (quarter-remainder) calendar then in use. He confirmed that the Moon's velocity varies, with the highest speed being at perigee. He also deduced that the point of maximum velocity shifts forward by 3 min of arc each month. Whereas ancient Chinese astronomers generally used polar and equatorial coordinates, Jia Kui advocated the use of ecliptic coordinates as the more accurate frame of reference for studying solar and lunar motions.

Jia Kui had bronze ecliptic instruments cast and put in use at the Imperial Observatory. Jia Kui pointed out that the equinoxes used in the previous Taichu calendar (104 BCE) had already moved to new locations. The precession of the equinoxes was not explained in China until the year 330, although its effects were noticed earlier. Nevertheless, Jia Kui's discovery was taken into account in improving the *Sifen* calendar.

Kevin D. Pang

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Johannes de Lineriis

➔ **John of Lignères**

Johannes de Muris

➔ **John of Muris [Murs]**

Johannes de Sacrobosco

➔ **John of Holywood**

John of Alexandria

➔ **Philoponus, John**

John of Gmunden

Born **Gmunden am Traunsee, (Austria), 1380–1384**
Died **Vienna, (Austria), 23 February 1442**

John of Gmunden, best known for his treatises on astronomical instruments such as the astrolabe and equatorium, made Vienna an important center of astronomy in Europe.

John, the son of a tailor in Gmunden, received his bachelor's degree at Vienna University in 1402, and his master's in 1406. His early university lectures (up to 1416) dealt mostly with philosophy and theology. Later (up to 1425), he lectured exclusively on mathematics and astronomy, and he became the first professor of these branches at Vienna University. John was twice dean of the university, and he gained many honors there.

In 1425 John became canon of Saint Stephan's cathedral in Vienna, but his university career continued with lectures on astronomy. He also wrote astronomical tables and treatises on astronomical instruments such as the astrolabe his version of the astrolabe is based on the influential treatises on construction and use of the astrolabe by Cristannus of Prachatics, quadrant, albion it is an extension of **Richard of Wallingford**'s text, equatorium, torquetum, cylinder, and nocturnal. Most of these treatises had remained in unpublished manuscripts until recently.

In his last years (1431—1442) John was a clergyman in Laa an der Thaya. In his will (1435) he bequeathed his books and astronomical instruments to the library of the Faculty of Arts of Vienna University. He is probably buried in Vienna's Saint Stephan cathedral.

John's successors in the university were **Georg von Peurbach** and **Johann Müller** (Regiomontanus). One should mention also the collaboration of John of Gmunden with the Czech astronomer John Sindel, who taught in Vienna from 1407 and who often met with him. John of Gmunden, John Sindel, and the prior of the monastery in Klosterneuburg, George Müstinger, were cornerstones of the first Viennese astronomical school.

Alena Hadravová and *Petr Hadrava*

Alternate name

Krafft, Johann

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John of Holywood

Flourished **first half of the 13th century**

John of Holywood wrote mathematical texts that were widely commented upon, corrected, and republished all over Europe. His work and that of his commentators was used for teaching astronomy for several centuries.

Almost no reliable information about the life of John of Holywood exists. On the basis of a statement made by his commentator Robertus Anglicus in 1271, he is generally considered to have been English by birth, but the possibility that he was of some other nationality has also been entertained by historians. His only known institutional connections were with the University of Paris, where John of Holywood is thought to have lectured on mathematics and astronomy; he may, however, have been educated elsewhere. After his death a memorial was erected in the Paris monastery of Saint Mathurin, which was closely associated with the university. This monument is no longer extant, but the record of its inscription has often been said to indicate that John of Holywood died in 1244 or 1256. These dates, however, have been derived not from the inscription itself, but from a few lines of verse found at the end of his *Compotus*, which bear a superficial resemblance to those of the monument; moreover, the lines are ambiguous – 1234 is another plausible interpretation of the signified date and one more consonant with the period of composition of the treatise itself – and the nature of the event to which they actually refer is unclear. It is fair to say, therefore, that the dates and circumstances of John of Holywood's life and death are equally obscure.

John of Holywood's most famous work, the *Tractatus de sphaera*, sets out the basic principles of spherical astronomy, from the divisions of the celestial sphere to the explanation of eclipses. His longest work, and the most sophisticated, is the *Compotus*. Datable to 1232–1235, this is a systematic treatment of calendrics and time-reckoning, which suggests a number of remedies for the calendrical discrepancies arising from use of the Julian scheme and the Metonic cycle equating 235 lunar months with 19 solar years. Thus, centuries before the Gregorian Reform, John of Holywood advocated the elimination of 10 days from the civil calendar, in order to restore the spring equinox to its rightful position (as he thought) of March 25th, and the omission of one leap year in 288 years, in order to prevent it drifting from this date again. He also suggested employing a 76-year sequence for the reconciliation of the solar and lunar cycles. But it seems that John of Holywood's calendrical ideas were heavily indebted to other calendrical writers, in particular to **Roger of Hereford** and to the unknown author of another 13th-century *computus*.

A more original text was his *Quadrans*, written *circa* 1245–1250, which describes the construction and use of the time-finding instrument known as the *quadrans vetus*; although related to other mathematical treatises, particularly the *Astrolabium* of pseudo-Messehallah, it seems to have been the first text devoted to this particular instrument. John of Holywood also wrote an *Algorismus*, which, although not an astronomical text, was described by **Peter Nightingale** as having been written for the good of astronomy. Since it outlined elementary arithmetical procedures, including the extraction of square and cube roots, it may indeed have been of some use in the education of astronomical practitioners, and it is frequently found bound with astronomical works in manuscript codices.

It is no longer thought that John of Holywood's works were written as university texts and employed in meeting the needs of the 13th-century curriculum. They were probably too sophisticated for the typical arts student, and would most likely have been studied as an extracurricular interest. Nevertheless, with the exception of the *Quadrans*, which was quickly superceded by the *Quadrans vetus* written by Johannes Anglicus, his texts were widely distributed in manuscript, attracted numerous medieval commentators, and continued to be read, reproduced, and annotated into the early-modern period. Indeed, with influential 16th-century pedagogues such as Philipp Melanchthon and **Christoph Clavius** sponsoring printed editions of the *Compotus* and *De sphaera* and promoting their use, John of Holywood's works were an established component of the university arts curriculum well into the 17th century.

Adam Mosley

Alternate names

Johannes de Sacrobosco
Sacrobosco

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John of Lignères

Born **Diocese of Amiens, (Somme), France, *circa* 1290**
Died ***circa* 1350**

John of Lignères helped to perfect the Latin Alfonsine Tables and is probably the central figure in their dissemination within Latin Christendom.

Except that John of Lignères lived in Paris about 1320 to 1335, little is known about his life. In the older literature his works were often confused among themselves and with those of other contemporary Paris astronomers named John: **John of Muris, John of Saxony, John of Speyer, John of Sicily**, and **John of Montfort**. John of Lignères, a mathematician and astronomer, appears to be the central figure in the dissemination of the Alfonsine Tables in the Latin West, with John of Muris and John of Saxony his most influential pupils. They worked together, and at least modified the tables, rendering them in a more practical form.

Concerning mathematics, John of Lignères was the author of one of the most important treatises on fractions in the Middle Ages. His work on astronomy, the *Canones super tabulas equationum* of *circa* 1320 (also referred to as the canons of the *Primum Mobile*) consists of three parts. The first deals with the astronomy of the associated tables. The second, *Priores astrologi motus corporum celestium* (edited by M. Saby-Rousset), dealing with planetary astronomy, is already based on the the *Expositio tabularum Alfonsi regis Castelle* of John of Muris (1321). But John of Lignères tried to go beyond it and carried out the astronomical calculations anew. His trigonometrical tables in the third part explained the new astronomical reflections concerning the Alfonsine Tables. These tables recall the structure and arrangement of the *Opus astronomicum* of **al-Battani**, the earliest Arabic compendium of Ptolemaic astronomy.

Around 1325 John of Lignères published a new set of canons, *Multiplicis philosophie variis radiis …*, the so-called *Tabule magne*, addressed to Robert Florence, dean of Glasgow. Since the old tables were inadequate, John established new ones for the Paris meridian. Since this required vast numbers of additions, multiplications, and divisions, he developed a *planetary equatorium*, an instrument of five parts enabling one to compute positions of the planets without extensive use of astronomical tables. Characteristics of the tables include 30° signs, the double-motion principle, the ninth sphere as the sphere of reference, and use of the Paris meridian.

A final significant work of John was a set of canons beginning *Quia ad inveniendum loca planetarum* to explain the use of what became the definitive version of the Alfonsine Tables in the European continent, written before 1327, when John of Saxony used them to produce his version of the canons, namely *Alfonsii regiis Castelle illustrissimi celestium motuum tabule* (edited by E. Poulle). The definitive version of the Alfonsine Tables is defined by their content:

(1) adoption of degree grouping into signs of 60° (instead of the "natural" 30° ones);
(2) variation of the mean motions presented in sexagesimal form (as in the Toledan Tables), explaining their universal applicability;
(3) adoption of a double motion of planetary "auges", *i. e.*, apogees, brought about by regular, precessional motion on the one hand and by access and recess motion (trepidational motion) on the other;
(4) choice of the ninth sphere (as of the Earth, opposed to the eighth of the stars and the apogees of the planets), as the seat of the mean coordinates; and
(5) a system of cylindrical radices (at least ten), taken from several calendars, including **Alfonso X**'s era (*i. e.*, 1 June 1252). The radices were usually given at 20-year intervals.

John of Lignères's astronomical work also included tracts on three instruments: the *equatorium* (already referred to), the *saphea* (an astrolabe with a peculiar system of stereographic projection), and a *directorium* (an instrument somewhat similar to the astrolabe, used for astrology).

Paul L. Butzer

Alternate name

Johannes de Lineriis

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John of [Juan de] Messina

Flourished **Toledo, (Spain), 13th century**

As one of approximately 50 Christian, Islamic, and Jewish scholars who worked under **Alfonso X**'s patronage in Toledo, in 1276 John of Messina edited **Abd al-Rahman al-Sufi**'s star catalog as *Los IIII Libros de la Ochaua Espera.* Based on a 1256 translation from Arabic to Castilian by Guillen Arremon Daspa and **Ben Solomon** ha-Kohen, *Los III Libros* was an important part of the Alfonsine corpus, *Libros del Saber de Astronomía*. John of Messina was aided by John of Cremona.

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John of Muris [Murs]

Born **diocese of Lisieux, (Calvados), France, *circa* 1290–1300**
Died **after 1357**

John of Muris paved the way for the Gregorian Calendar of 1582 and added basic new ideas to the Castilian Alfonsine Tables, if he was not the initiator of the (Latin) Alfonsine Tables.

Born in an aristocratic family, John studied at the Sorbonne in 1317–1321, and became a magister of the quadrivium. In 1326/1327 he was living at Fontevrault Abbey as a monk. Pope John XXII conferred the benefice of Le Bec Hellouin Abbey in 1329, and in 1332/1333 John called himself rector of the school in Evreux, living at the court of Philippe III of Navarre 1337–1342. John travelled continuously, never staying long at any one place, working steadily and meeting scholars of various fields during his travels. Thus, he was at Mézières-en-Brenne (1342) at Avignon (1344) together with Firminus de Bellavalle at the invitation of Pope Clemens VI to reform the antiquated calendar, where he met Jewish scientists (*e. g.*, Salomon, brother of **Levi ben Gerson**) then again at Paris (1346) and in England (1357).

John of Muris was the author of several dozen texts on arithmetic and geometry, music, and astronomy, including computus and astrology. His achievements were already recognized during his lifetime. His work in mathematics was critical to his calculations in astronomy. The handbook *De arte mensurandi* of *circa* 1343, in 12 chapters, deals in part with the mathematical knowledge necessary for astronomy. Sources cited include Abu Bakr's *Liber mensurationum* and Leonardo Fibonacci's *Liber abaci.* In his *Quadripartitum numerorum* of 1343, the use of decimal fractions in the particular case of extraction of square roots is noteworthy. John also authored a short treatise on trigonometry entitled *Figura inveniendi sinus kardagarum*, with a construction of a sine table, needed for his astronomy.

In astronomy, John of Muris's name, like those of **John of Lignères** and **John of Saxony**, is associated with the Alfonsine Tables. He did not try to improve the old Latin calendar, as did his predecessors, but *corrected* the calendar, using new literature, ideas, and aspects. His treatises, tables, and reputation led Pope Clemens VI to invite him to Avignon. John's first tract, *Autores kalendarii* of *circa* 1317, deals with the problems of computing the date of Easter. (The vernal equinox in 1308 actually was on 13 March, so that Easter should have been celebrated earlier, the calendrical date being 8 days earlier than the astronomical one.) He preferred the sexagesimal system, as used in the Toledan Tables.

John's *Expositio intentiones regis Alfonsi circa tabulas ejus* (1319, 1321) is the first treatise to be concerned with an exposition of the Alfonsine Tables, regarded as very exact and based on numerous astronomical observations. John learned of their existence between 1317 and 1319. Since he had no command of Castilian, he probably had a Latin translation of the originals, commissioned by **Alfonso X**. Characteristics of John's version include 60° signs (but with simultaneous use of 30° ones), double motion of the apogees, and reference to the ninth sphere. His *Patefit* of 1321, understandable by nonprofessionals, is concerned with astronomical aspects in correcting the calendar. The meridian of Toledo was still the basis for John's calculations, although he mentioned the Alfonsine Tables. His calendar began with the year 1321 and was limited to 1396.

John's *Tabule principales*, accompanied by concise canons and preserved in Lisbon and Oxford, is roughly contemporary with those of John of Saxony (1327); they are among the original highlights of medieval astronomy. The main principle is to exploit a list of dates and positions of the mean conjunctions of the Sun and each of its planets; these lists are rectified using a double-entry table, the *contratabula*. They use 60° signs and the Toledo meridian. Basic again is the double motion of the apogees and the adoption of the ninth sphere with its tropical coordinates, characteristics apparently opposed to the Castilian Tables.

The *Sermo de regulis compotistarum quia cognite sunt a multis* ..., dated to 1337, is again concerned with replacing the ecclesiastical calendar by a chronological instrument conforming to astronomical reality. The Alfonsine Tables were now in full use.

The *Ad correctionem calendariii*, the shortest of his computistical tracts, is almost a prototype of John's *Epistola super reformatione antiqui kalendarii* of 1345/1346, a systematic, clearly arranged but demanding work consisting of four tracts and 12 chapters, and is his most widely disseminated work. The work, perhaps coauthored with Firmin de Bellavalle, was a response to Pope Clemens' invitation to Avignon. John explained in tract 4 the basic consequences of his suggestions for a calendar reform, without giving preference to any solution. Leaving out a few days would lead to the desired solution, but he left the choice to the pope and the church.

The pope dissolved the reform commission in 1345 for various reasons. John's concrete suggestions did not yet lead to the expected correction – the Julian calendar was retained for two further centuries – but their quality was a basis for the Gregorian reform of 1582.

Paul L. Butzer

Alternate names

Jean de Meurs
Jehan de Murs
Johannes de Muris

Acknowledgment

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John [Danko] of Saxony

Flourished ***circa* 1320–1355**

John of Saxony was a pupil of and worked with **John of Lignères** in Paris on a Latin version of the Alphonsine Tables. These tables for calculating planetary positions, prepared under the auspices of **Alfonso X**, were originally in Spanish. John of Saxony wrote canons (explanations of the use) of the Latin version of the tables, which helped in spreading their use throughout Europe. In 1331 he also wrote a commentary on a work on astrology by **Qabīṣī**, being careful to say nothing the church might object to. John calculated an Almanac for 1336–1380, based on the Alphonsine Tables as adapted for the Paris meridian.

Katherine Bracher

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John of Toledo

Flourished **12th century**

In 1185 John predicted a massing of all naked-eye planets for the following year. The event was to be accompanied by the appearance of the anti-Christ.

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John the Grammarian

Philoponus, John

Johnson, Manuel John

Born **Macao, China, 23 May 1805**
Died **Oxford, England, 28 February 1859**

Star cataloger Manuel Johnson founded an observatory at Saint Helena, prepared one of the earliest accurate catalogs of Southern Hemisphere stars, and served as director of the Radcliffe Observatory. The only son of John William Johnson, he attended Addiscombe College, the British East India Company's military academy. Commissioned as a lieutenant at age 16, he was assigned to an artillery unit stationed on the island of Saint Helena. Johnson developed an interest in astronomy, which was encouraged by the governor of the island who wished to establish an observatory there. Johnson made two trips to Cape Town, South Africa, in 1825 and 1828, to confer with **Fearon Fallows**, His Majesty's Astronomer at the Cape, on observatory construction and equipment.

Johnson began observation at Saint Helena late in 1829. Over the next 4 years he compiled a catalog of 606 Southern Hemisphere stars, which was printed at the company's expense in 1835. In that same year the Saint Helena Artillery was disbanded, and Johnson returned to Britain to receive the Royal Astronomical Society's Gold Medal.

Although he was of a somewhat mature age, Johnson matriculated at Magdalen Hall, Oxford University, in December 1835. He graduated with a BA in 1839, in time to apply for the vacancy in the Radcliffe Observatory at Oxford. Johnson received the appointment and held this position for the rest of his life. During his tenure, the Radcliffe Observatory acquired a transit-circle by Simms and a Repsold heliometer. He observed double stars and measured the parallaxes for Castor, Arcturus, and Deneb.

Johnson was elected to the Royal Society in 1856 and served as president of the Royal Astronomical Society in 1856/1857. He married Caroline Ogle in 1850. After an extended illness Johnson died of heart disease.

Keith Snedegar

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Jonckheere, Robert

Born **Roubaix, Belgium, 25 July 1888**
Died **probably Marseilles, France, 27 June 1974**

Robert Jonckheere was one of the leading double star discoverers of the 20th century. As the son of a Belgian industrialist, Jonckheere developed an early passion for astronomy and exhibited talent in this area because of his acute vision. His father provided an observatory equipped with an 8.7-in. refractor at their home in Roubaix in 1905. Young Jonckheere joined the Société Astronomique de France [SAF] in that same year and published his early results in the *Comptes rendus de l'Academie des sciences*, *The Observatory*, and the *Monthly Notices of the Royal Astronomical Society*. By 1908, it was clear that a larger telescope in a darker area would benefit Jonckheere's observation program, so he constructed a new observatory at Hem, near Lille, in 1908 and commenced a program of observation and discovery of double stars. From 1908 to 1914, Jonckheere discovered 1,067 new faint (between 9th and 15th magnitudes) double stars with an average separation of only 3.09″, a performance that placed him in the same league of double-star observers as **Sherburne Burnham**, **Robert Aitken**, and **William Hussey**.

Displaced to England by the German invasion of 1914, Jonckheere divided his time between the Optical Service of the Royal Arsenal and observing double stars using the 28-in. refractor of the Greenwich Observatory, under the sponsorship of Astronomer Royal Sir **Frank Dyson**. While there, Jonckheere added another 252 discoveries of double stars to his catalog. In 1917, the Royal Astronomical Society published Jonckheere's catalog of observations of 3,950 double stars, of which 1,319 were his own discoveries. On the basis of that work, the French Academy of Sciences awarded him its Lalande Prize.

In 1919 Jonckheere returned to Lille to find that the observatory at Hem had been severely damaged during the war. The cost of restoring and maintaining the observatory was prohibitive, so the observatory was turned over to the University of Lille. In 1929, when the Marseilles Observatory offered him the opportunity to move to a more favorable location, Jonckheere quickly accepted. In Marseilles, he continued his lifetime vocation of double star observation. In 1942, Jonckheere was granted a governmental position as a research master for the National Center for Scientific Research. At that time, the Marseilles Observatory director, J. Bosler, turned over to Jonckheere the historic 31.5-in. reflecting telescope built by **Leon Foucault**. After significant effort to restore this telescope, Jonckheere returned it to useful service. For this accomplishment, the Academy of Sciences awarded him its Becquerel Prize in 1943. Thereafter, Jonckheere divided his time between the large reflector in Marseilles and the refractors at Nice, Strasbourg, and Toulouse. Late in his career, Jonckheere published, with the assistance of the International Astronomical Union, a catalog of his observations, including his 3,350 faint double star discoveries, made between 1906 and 1962.

In 1964, **Rudolph Minkowski** confirmed that three faint nebulae discovered visually by Jonckheere were in reality previously unknown elliptical galaxies, which resulted in yet a third award from the Academy of Sciences.

Thomas R. Williams

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Jordan, Ernst Pascual

Born **Hanover, Germany, 18 October 1902**
Died **Hanover, Germany, 31 July 1980**

In the cosmology of physicist Pascual Jordan, **Isaac Newton**'s gravitational constant is replaced with a term that varies with time. Jordan also helped found quantum mechanics, which describes many astrophysical processes.

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Joy, Alfred Harrison

Born **Greenville, Illinois, USA, 23 September 1882**
Died **Pasadena, California, USA, 18 April 1973**

American spectroscopist Alfred Joy was the first to recognize that the T Tauri variables are very young dwarf stars and thus provide direct evidence of ongoing star formation, and the first to determine spectroscopic binary orbits for cataclysmic variable stars. Joy received a BA in 1903 from Greenville College, Illinois, and an AM in 1904 from Oberlin College, Ohio. The degree was in physics, but the greatest influence on him was unquestionably astronomer **Charles St. John**. Joy taught physics and astronomy at the Syrian Protestant College (later American University) in Beirut, Lebanon, during 1904–1914. His summers and sabbaticals were spent in Egypt (for the solar eclipse of 1905), at Oxford University and at Cambridge University (working on the *Carte du Ciel* in 1909 with **Herbert Turner** and **Arthur Hinks**), at Yerkes Observatory (doing objective-prism spectral classification in 1910), at Princeton University (with **Henry Norris Russell** in 1911), and at Potsdam (working under **Karl Schwarzschild** and **Ejnar Hertzsprung** in 1914). He was appointed to the staff of Mount Wilson Observatory in 1915 and remained there until his death. Joy was a guest lecturer in astronomy at the California Institute of Technology in 1949–1953, while **Jesse Greenstein** was building up the department.

In 1919, Joy married Margherita O. Burns (a member of the Mount Wilson computing staff). She and their children (Edith and Richard, at one time a flight engineer for Pan American Airways) survived him.

Joy's work was somewhat compartmentalized into major studies completed with a definitive paper every half decade, beginning with spectroscopic parallaxes of 7,000 stars in 1915. Next, he, **Ralph Wilson**, and **Gustav Stromberg** measured the radial velocities of 5,000 stars, using them to trace out galactic rotation and determine the motion of the Sun relative to its neighbors. His detailed study of changes of the spectrum of Mira (o Ceti) during its declines from maximum brightness led to the 1920 discovery of its faint, white dwarf companion.

During the 1930s, Joy followed the spectra of 128 Cepheid variables throughout their periods of variation, showing that the phasing of their pulsation versus brightness was not the simple small-equals-hot relation that had been expected. He also used these stars to derive galactic rotation and the direction and distance to the galactic center. He measured and the average amount of interstellar extinction, scattering, and absorption of light which could then be used as distance indicators for other stars. His numbers were one magnitude of extinction and scattering (by dust) per kiloparsec, or seven clouds of absorbing gas per kiloparsec, both in the galactic plane. During the same period, Joy assembled data on the RV Tauri stars and related classes of (cool, evolved) semiregular, giant variables, showing that, if they were grouped by kinematics, brightness, distribution in space, spectral types, and carbon band strength, they bifurcate, in ways that are now recognized as characterizing the stellar populations I and II later described by **Walter Baade**.

The most important of Joy's contributions came still later, in the 1940s and 1950s, and arose out of his interest in the spectra of intrinsically faint variable stars (on which he wrote the definitive review article in 1959). One of these was investigation of the variable class he called SS Cygni or U Geminorum stars (now more often called dwarf novae, because of their frequent, modest outbursts). Joy showed that two of these, AE Aquarii and SS Cygni itself, are binary systems with periods of 0.70 and 0.276 days, requiring the stars to be very compact. Later work by **Otto Struve** and Robert Kraft showed that duplicity is universal in the class. It was already clear to Joy that one of the stars had to be something like a white dwarf, and this proved crucial to understanding the outbursts, which arise from unstable transfer of gas from the cool star to the white dwarf.

In two papers in 1945 and 1950, Joy described the class of T Tauri variables, characterized by numerous, bright, variable emission lines (like those produced in the solar chromosphere) and by proximity to both dark and illuminated clouds of relatively dense gas and dust. Joy deduced that these stars must be accreting from the clouds and so represent the transition phase from diffuse material to stars of relatively small mass (*i.e.*, star formation). The phase had previously been missing from inventories of the stages of stellar evolution, and, indeed in 1945, many astronomers doubted that low mass star formation was an ongoing phenomenon. Following his mandatory 1948 retirement, Joy devoted a good deal of attention also to the class of M dwarfs called UV Ceti stars, which experience occasional flares, much brighter than solar flares relative to the star's average luminosity.

The Joy anecdote most often recounted was his 1946 fall from the Cassegrain platform of the 100-in. telescope at Mount Wilson Observatory, when the platform was about 20 ft. above the cement floor of the dome. He was back at the telescope in just a few months.

Joy was a member of the United States National Academy of Sciences (1944) and a foreign associate of the Royal Astronomical Society. He served as secretary of Mount Wilson Observatory from 1920 to 1948 and as president of the American Astronomical Society (1949–1952). Joy was twice president of the Astronomical Society of the Pacific (1931–1933 and 1939–1941), edited its leaflets for the general public (1945–1968, writing a good many himself), and received the Society's Bruce Medal in 1950. His *alma mater*, Greenville College, awarded him an honorary Sc.D. in 1945.

Helmut A. Abt

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Jurjānī: ʿAlī ibn Muḥammad ibn ʿAli al-Ḥusaynī al-Jurjānī (al-Sayyid al–Sharīf

Born **Taku (near Astarābādh, Gurgān, Iran), 1340**
Died **Shiraz, (Iran), 1413**

Jurjānī's contribution to astronomy is in his role as commentator on several significant astronomical texts of his time. Jurjānī's interest in science and philosophy is evident in his journey to Herat (Afghanistan) to study with the aged Quṭb al-Dīn Muḥammad al-Rāzī (died: 1365), who wrote on logic, philosophy, and theology. Al-Rāzī was a student of the Shīʿī scholar ʿAllāma al-Ḥillī (died: 1325), who in turn had studied with the astronomer, philosopher, and theologian **Naṣīr al-dīn al-Ṭūsī** at the Marāgha Observatory. Pleading advanced age, al-Rāzī declined Jurjānī's request to study with him, recommending instead that Jurjānī study with his student Mubārakshāh, who was known as "the logician" (*al-Manṭiqī*), in Cairo. Jurjānī's subsequent journey to Cairo took 6 years as he traveled and studied with scholars. In 1371, Jurjānī arrived in Cairo to study religious, linguistic, and rational disciplines. Four years later, he returned to Iran by way of Constantinople, then under Byzantine rule. In 1377 he was invited to join the court of the Muẓaffarid ruler Shāh Shujāʿ (reigned: 1353–1384) in Shiraz. Following Tamerlane's capture of Shiraz in 1387, Jurjānī was forced to relocate to Tamerlane's court in Samarqand. Here he encountered the elderly distinguished scholar Saʿd al-dīn al-Taftazānī (died: 1390), who had also been brought to Samarqand by Tamerlane. Like Jurjānī, al-Taftazānī had written commentaries on works in several disciplines, but from a conservative perspective. Jurjānī engaged him in several debates in the presence of Tamerlane. After Tamerlane's death in 1405, Jurjānī returned to Shiraz where he resided until his death.

Jurjānī lived during the turbulent aftermath of the Mongol conquest of the lands of Islam up to the emergence of the Timurid empire. Intellectually, this period is characterized by the proliferation of commentaries, supercommentaries, and glosses on the "canonical texts" of various disciplines. Jurjānī's voluminous writings, of about 100 works, are characteristic in this regard. The 16th-century historian Khwāndamīr noted that Jurjānī "has glosses on most books by the ancients and moderns in the curriculum. Indeed, from his own time until the present, no lesson is given without the benefit of his glosses and studies."

Jurjānī cannot be considered an astronomer in the strict sense – he was neither engaged in observational nor in theoretical astronomy. Nor is he the author of independent astronomical treatises. His astronomical writings, that is to say, commentaries on the significant astronomical texts of his time, are a small part of his total corpus. These consist of his commentaries on Ṭūsī's *The Memoir on Astronomy*, **Quṭb al-Dīn al-Shīrāzī**'s *The Imperial Gift*, and **Maḥmūd al-Jaghmīnī's** *The Compendium of Cosmology*. His grasp of astronomy is evident in these commentaries. He even suggests textual emendations to the manuscripts he had consulted. While multiple copies of these commentaries have survived, the task of editing and publishing them is still incomplete.

Besides these "purely" astronomical texts, Jurjānī participated in the wider dissemination of astronomy *via* his commentaries on theological texts, which were part of the curriculum of the religious colleges (*madrasas*). The universe and its constituents is a standard motif of these texts. In his commentaries on Ṭūsī's *Paring Down to the Articles of Faith* and ˁAḍud al-Dīn al-Ījī's (died: 1355) influential theological text *Stations of the Discipline of Kalām* as well as his supercommentary on al-Razī's *Commentary on the Risings of Light*, Jurjānī supplements, explains, and glosses discussions related to astronomy. Jurjānī's commentaries became the subject of further supercommentaries and glosses. In this manner, aspects of astronomy were scholasticized and persisted for centuries in religious colleges *via* their inclusion in theological texts. This could include new observational findings; regarding precession, Jurjānī, in his commentary on the *Stations*, tells theology students: "a group of recent investigators who have determined that it describes one degree every seventy years which confirms the new measurements made at Maragha." Also included was the important distinction between "fact" and "reasoned fact," the former being within the purview of the astronomer while the latter was for the natural philosopher to determine. Since many doctrines of the natural philosophers were suspect from the point of view of Muslim theologians (such as **Aristotle**'s insistence upon the necessity of nature and the immutability of the celestial realm), a number of other views were put forth and debated, such as the possibility of void space and the expansion and contraction of the celestial sphere, in order to maintain God's omnipotence and volition.

Another point of debate in these theological texts was the question of the reality of the celestial orbs. Al-Ījī had declared that they were imaginary, no more real than a "spider's web." But Jurjānī disagreed: "Even though the circles have no external reality, being imaginary entities, they are still valid imaginary entities corresponding to what actually is the case … they are not invalid imaginary entities such as fangs of ghouls or ruby mountains or two-headed humans!" For Jurjānī, the astronomer's role was to understand God's creation, thereby glorifying its wondrousness.

Alnoor Dhanani

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Jūzjānī: Abū ˁUbayd ˁAbd al-Wāḥid ibn Muḥammad al-Jūzjānī

Flourished **(Iran), 11th century**

Jūzjānī was one of the earliest Islamic scientists to provide an alternative to **Ptolemy**'s equant model. Very little is known about his life. He probably was already a jurist (*faqīh*) in Jurjān when he met **Ibn Sīnā** in 1012. He became one of his students and tells us that he studied Ptolemy's *Almagest* and logic with Ibn Sīnā. He aided Ibn Sīnā with the compilation of the *Cure* (*al-Shifā'*) and added the sections on geometry, arithmetic, astronomy, and music from Ibn Sīnā's earlier works to the *Salvation* (*al-Najāt*) as well as the *Philosophy* for ˁAlā al-dawla (*Dānishnāme-i ˁAlā'ī*). Jūzjānī commented on the difficult passages of Ibn Sīnā's *Canon of Medicine* (*al-Qānūn fī al-ṭibb*) and translated the "Book on Animals" of the *Cure* from Arabic into Persian. He completed Ibn Sīnā's *Autobiography* after his death. Jūzjānī is also the author of *The Manner of Arrangement of the Spheres* (*Kitāb Kayfiyyat tarkīb al-aflāk*), which has not survived, as well as a surviving *Summary* (*Mulakhkhaṣ*) of this work. Finally, he is the author of *Summary of the Arrangement of the Spheres* (*Khilāṣ tarkīb al-aflāk*), which is a commentary on **Farghānī**'s influential *Elements of Astronomy and Celestial Motions* (*Jawāmiˁ ˁilm al-nujūm wa-'l-ḥarakāt al-samāwiyya*).

In his *Summary of The Manner of Arrangement of the Spheres*, Jūzjānī tells us of his abiding interest in astronomy and his difficulty comprehending the equant and the components of motion in latitude (inclination, twisting, and slant of the epicycle). He turned to Ibn Sīnā for guidance and was told: "I came to understand the problem after great effort and much toil and I will not teach it to anybody. Apply yourself to it and it may be revealed to you as it was revealed to me." Jūzjānī was skeptical of Ibn Sīnā's claim for he states: "I suspect I was the first to achieve an understanding of these problems." Jūzjānī's issue with the equant is that "we know that the motions of celestial bodies cannot be nonuniform, so that they are at times faster and at times slower. This has been demonstrated in physics (*al-ˁilm al-ṭabīˁī*)." Jūzjānī proposes to "solve" the equant problem with a model in which all spheres (the deferent, the epicycle, and a secondary epicycle) move at uniform speeds around their centers. However, the model is unworkable.

The significance of Jūzjānī's critique of the equant does not lie in his unworkable solution but rather in the fact that his contribution is independent of the critique of the equant in the work of his elder contemporary **Ibn al-Haytham** entitled *Doubts against Ptolemy* (*Shukūk ˁalā Baṭlamyūs*). These represent the earliest known critiques of Ptolemy's equant hypothesis, which ultimately led to alternative models formulated by **Naṣīr al-Dīn al-Ṯūsī** and others (sometimes referred to as the "Marāgha School") regarding planetary motion that did not resort to the equant. While Ibn al-Haytham's critique seems to have been more influential, the Marāgha astronomers were aware of Jūzjānī's contribution. In his polemical *You Did It, So Don't Blame Me!* (*Faˁalta fa-lā talum*), **Quṭb al-Dīn al-Shīrāzī** preserves an extensive reference to Jūzjānī's effort.

Alnoor Dhanani

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Jyeşţhadeva

Flourished **(India), 16th century**

Jyeşţhadeva was the pupil of **Nīlakaṇṭha I** and teacher of **Acyuta Piṣāraṭi**. He wrote one of the main texts of the Kerala tradition.

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K

Kaiser, Frederik [Frederick, Friedrich]

Born **Amsterdam, the Netherlands, 10 June 1808**
Died **Leiden, the Netherlands, 28 July 1872**

Frederik Kaiser directed the Leiden Observatory from 1837 until his death in 1872. His contributions to Dutch astronomy included the foundation of a completely new observatory building in Leiden (in 1860, the first of its kind in the Netherlands) and the introduction of statistics and precision measurements in daily astronomical practice. Moreover, he was a gifted teacher and a skillful popularizer of astronomy.

Kaiser was the oldest boy of eight children born to Johann Wilhelm Keyser and Anna Sibella Liernur. His parents were immigrants from Nassau-Dietz in Germany. Kaiser's father, a teacher of German, died in 1817 when Frederik was 8 years old. Kaiser was then raised by his uncle, Johan Frederik Keyser, a municipal employee and teacher of mathematics in Amsterdam. Keyser was a member of several learned societies and was known as a proficient amateur astronomer; he is said to have been the first to give a reasonable determination of the geographical coordinates of Amsterdam. In his young nephew Frederik, Keyser discovered a talent for mathematics and observational astronomy, and he decided to teach him the trade.

When Keyser himself died in 1823, the 15-year-old Kaiser took over his uncle's job as a teacher of mathematics; with his uncle's books and instruments, he further educated himself in the science of astronomy. By then, he had already published his first article, reporting his calculations of an occultation of the Pleiades by the Moon.

Kaiser owed much to his uncle's colleagues for his university career. While the Dutch government could not provide Kaiser with a scholarship, **Gerard Moll**, director of the Utrecht University Observatory and a former pupil of Keyser, found a place for Kaiser as an observer at the Leiden Observatory, then a small construction on top of the academy building. His was the first professional post as observer in the country (1826). But to his disappointment, Kaiser found the observatory's instruments old and broken, its structure unstable, and he did not get along well with its director, Pieter Johannes Uylenbroek, who was uninterested in practical astronomy. Kaiser borrowed a telescope and conducted better observations at home.

Kaiser earned his bachelor's degree in mathematics and physics in 1831; the same year he married Aletta Rebecca Maria Barkey. The couple had one daughter and four sons, of whom one died in infancy. The third son, Pieter Jan Kaiser, later became an astronomer and succeeded his father as instrument controller for the Dutch Navy.

Better astronomical times were in store for Kaiser in 1835, when he received an honorary doctorate from the University of Leiden for his work on Halley's comet (IP/Halley). This study included an improved prediction of the comet's perihelion passage and a highly valued popular book on the subject. Kaiser's recognition was followed by his appointment as lecturer and director of the observatory in 1837, extraordinary professor of astronomy (the first Dutch professoriate in astronomy) in 1840, and ordinary (full) professor in 1845.

Thus, Kaiser found himself in a position to make the most necessary changes to the observatory. He improved the construction of the building and purchased some new, high quality instruments, including a 6-in. Merz refractor. He also developed a master plan for what he called the "revival of Dutch astronomy." Kaiser's notion encompassed (1) promotion of the practice of astronomy at Leiden University by providing better education, (2) instruction of the general public by means of popular works, and (3) increasing international awareness of Dutch astronomical research through publication. Kaiser's long-term efforts in this enterprise made him the key figure in the professionalization of 19th-century Dutch astronomy.

A series of fundamental observations was commenced in 1840. Kaiser concentrated on positional astronomy and continued this as the observatory's policy throughout his life. He was the first to introduce statistical methods and precision measurement in Dutch astronomy, and wrote several works on the use of the micrometer and the determination of the "personal equation" of the observer.

Kaiser also became known for his lectures in popular astronomy and his many articles in popular magazines. His writings were often accompanied by complaints about the state of astronomy in the Netherlands, which helped to foster public opinion for the science of astronomy. In that context, Kaiser's most appreciated work was *De Sterrenhemel* (1844–1845), an overview of astronomical theory and practice for the layman. It appeared in two volumes and four editions; parts of it were translated into German, Danish, and French.

Kaiser's public persona was of considerable benefit in raising the funds for a new observatory. He had long planned a new, up-to-date building, based on models from Germany and the Pulkovo Observatory (Saint Petersburg, Russia). The Dutch government, however, was not eager to support his initiative. After many years of fruitless lobbying, a national fundraising campaign for Kaiser's observatory was inaugurated. It was successful, and when the government provided the remaining funds, a fully equipped observatory building was finished (1860), the first of its kind in the Netherlands. Instruments included a state-of-the-art meridian circle by Pistor and Martins and a 7-in. Merz refractor. The staff was enlarged with an extra observer and some calculators.

Kaiser then initiated an extensive observational program. From 1864 to 1868, the fundamental parameters of some 180 stars were measured, followed by 202 stars for the *Europäische Gradmessung* (European Geodetic Survey). The results were published in 1868. Further work at the observatory was done on micrometer measurements of binary stars and planetary diameters, comets, and the rotation period of Mars. Between 1870 and 1876, the observatory participated in the observation of zones for the star catalog of the Astronomische Gesellschaft.

Kaiser had occupied astronomy-related functions as supervisor of the geodetic survey of the Dutch East Indies (1844–1857), as the founding director of the institute that controlled the calibration of instruments for the Dutch Navy (1858), and as a Dutch delegate and board member in the *Europäische Gradmessung* (1867). He was a member of the Royal Dutch Academy of Sciences, the Holland Society of Sciences, the Royal Astronomical Society, the Prussian Academy of Science, and the Astronomische Gesellschaft. In 1845, he was awarded the Dutch knighthood.

Kaiser's health had always been precarious. After a severe illness in 1867, he had to abandon his nightly observational routine. The death of his wife in 1872 dealt him a second blow, from which he did not recover. Kaiser was succeeded as director of the observatory by **Hendrik van de Sande Bakhuyzen**.

Many a scientist of the next generation was stimulated by Kaiser's lectures. Among his students we find the astronomers Van de Sande Bakhuyzen, **Martin Hoek**, and Jean Abraham Chretien Oudemans, who completed their doctoral research at Leiden Observatory. Also inspired by Kaiser's teachings were **Hendrik Lorentz**, Johannes Bosscha (later director of the Delft Polytechnical Institute), and chemist Johannes Diderik van der Waals. Thus, Kaiser initiated the dissemination of a new level of precision in Dutch science.

Craters on the Moon and Mars are named for Kaiser.

His papers may be found at the Leiden Observatory and Leiden University Library, the Archief van de Rijkscommissie voor Geodesie (Delft), and the Instituut voor Maritieme Historie (the Hague).

Petra van der Heijden

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Kãllippow

➔ **Callippus of Cyzikus**

Kaluza, Theodor Franz Eduard

Born **Ratibor (Racibórz, Poland), 9 November 1885**
Died **Göttingen, (Germany), 19 January 1954**

German mathematician Theodor Kaluza, together with **Oskar Klein,** gave his name to the Kaluza–Klein theories of physics in which space–time has five dimensions rather than the four of **Albert Einstein**'s equations of general relativity. Kaluza studied at Königsberg (now Kaliningrad, Russia), receiving a doctorate in 1910 for a thesis on a mathematical topic called Tschirnhaus transformations. He remained at Königsberg as a *Privatdozent* (lecturer) for nearly 20 years (a very long period in this low-level position) until, at the urging of Einstein, the University of Kiel appointed him to a minor professorship. Kaluza finally became full professor at the University of Göttingen in 1935, dying very shortly before he would have retired.

The idea for which Kaluza was remembered appeared in a 1919 letter to Einstein, in which he suggested writing the field equations of general relativity in five dimensions. The new equations contained within them Einstein's original four-dimensional theory plus a new piece that turned out to be exactly the theory of light (electromagnetism) of **James Maxwell**. The fifth dimension was in the shape of a cylinder, assumed by Kaluza to be of macroscopic size. Two years later, Einstein communicated the paper for publication. It was widely thought to be too mathematical to have any connection with the real world. In 1926, Klein heard of Kaluza's work from Wolfgang Pauli, and, while describing it as a shipwreck, really made only one major change. The cylindrical fifth dimension was curled up in a ball the size of the Planck length, 10^{-33} cm, making it undetectable. But this meant that it did not violate any experiments. The outcome of this work was a new branch of field theory known as the Kaluza–Klein theory. The Kaluza–Klein theory held some interest in theoretical physics for a few years, but by the 1930s the theory was dead at least temporarily. A renaissance occurred in the early 1980s when many physicists realized the power multidimensional analysis held. What they did was to extend Kaluza–Klein theory to N dimensions allowing them to add symmetry to hyperspace. When these N dimensions were curled up like the fifth dimension in the Kaluza–Klein theory the celebrated Yang–Mills field of the Standard

Model of particle physics popped out of the equations! This marked the beginning of the very active fields of superstring theory and supergravity. Thus Kaluza's legacy lives on today in these theories as well as in the Kaluza–Klein theory itself. A version with $N = 11$ became quite popular near the turn of the century. The lowest-mass Kaluza-Klein particle is a possible dark matter candidate.

Ian T. Durham

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Kamāl al-Dīn al-Turkmānī: Kamāl al-Dīn Muḥammad ibn Aḥmad ibn ÀUthmān ibn Ibrāhīm ibn Muṣṭafā al-Māridīnī al-Turkmānī al-Ḥanafī

Born **Cairo, (Egypt), 1314**
Died **probably Gülistan (Guliston, Uzbekistan), after 1354**

Kamāl al-Dīn al-Turkmānī was one of several writers who wrote a commentary to **Jaghmīnī**'s *al-Mulakhkhaṣ fī ˁilm al-hay'a al-basīṭa*. Most of his other writings are in the fields of history and *fiqh* and *uṣūl* (Islamic law and jurisprudence). There is much confusion regarding his education, life, and date and place of death. However, we do know that Kamāl al-Dīn al-Turkmānī was born and spent some time in Cairo (where he undoubtedly benefited from the scientific environment), and that he also lived much of his life in Mardin (now in southeastern Turkey). He came from a family that was actively engaged in scientific work; most likely he was first educated by his father Aḥmad, known as Ibn al-Turkmānī, who was an astronomer who had written a commentary on **Kharaqī**'s astronomical treatise *al-Tabṣira fī ˁilm al-hay'a*.

Kamāl al-Dīn al-Turkmānī's *Commentary* to the *Mulakhkhaṣ* was written in September 1354 in Gülistan/Saray, the capital city of the Golden Horde State, and was offered to Jānī Beg Khan (reigned: 1349–1352); the work is a significant indication of how widespread and established the Islamic scientific heritage had come to be. The *Commentary* was used as a textbook for studying *ˁilm al-haya* (theoretical astronomy) throughout the Ottoman Empire and Persia for many years. At least ten copies of the work can be found today in Turkey's manuscript libraries (the oldest copy being Atıf Efendi Library MS 1707/2, 11b–223a). In addition, Fasīh al-Dīn Muḥammad al-Kūhistānī (died: 1530), who was a student of **ˁAlī al-Qūshjī**, wrote a supercommentary on Kamāl al-Dīn al-Turkmānī's *Commentary*. This represents an important indication of the continuous tradition of studying *hay'a* within the Samarqand school of mathematicians and astronomers.

İhsan Fazlıoğlu

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Kamalākara

Born **Vārāṇasī, (Uttar Pradesh, India), *circa* 1608**

Kamalākara was born into a learned family of scholars from Golagrāma, a village on the northern bank of the river Godāvarī. Kamalākara was the second son of Nṛsiṃha, himself a scholar. His family later moved to Vārāṇasī. Many members of Kamalākara's family were illustrious astronomers, many of whom were also original discoverers. All of them have contributed to the literature on astronomy. Kamalākara learnt astronomy from his elder brother Divākara, who compiled five works on astronomy. Kamalākara cites from Divākara's works.

Kamalākara's major work, *Siddhāntatattvaviveka*, was compiled in Vārāṇasī at about 1658 and has been published by Sudhākara Dvivedi in the Vārāṇasī series. This work consists of 13 chapters in 3,024 verses in different meters and treats such topics as mean positions and true positions of planets, shadows, elevation of the Moon's cusps, rising and settings, eclipses, *etc.* Although this text borrows heavily from *Sūryasiddhānta*, it contains some things not found in other texts. For example, Kamalākara states that the pole star we see at present is not exactly at the pole. He has assumed a value of 60 units for the radius of the Earth and gives values for sines at 1° intervals. Kamalākara also gives a table for finding the right ascension of a planet from its longitude. According to D. Pingree, he presents the only Sanskrit treatise on geometrical optics. His other works include *Śeṣavāsanā* and *Sauravāsanā*.

Kamalākara was bitterly opposed to Munīśvara, the author of *Siddhāntasārvabhauma*.

Narahari Achar

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Kanka

Flourished **Ujjian, (Madhya Pradesh), India, *circa* 770**

According to tradition, Kanka was brought to Baghdad by the caliph to teach the Arabs Hindu astronomy. Kanka carried with him the *Brāhmasphuṭasiddhānta* of **Brahmagupta.**

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Kant, Immanuel

Born **Königsberg (Kaliningrad, Russia), 22 April 1724**
Died **Königsberg (Kaliningrad, Russia), 12 February 1804**

Immanuel Kant, one of the greatest philosophers of modern times, was one of the first to envision a Newtonian cosmogony. Born into a family of artisans, Kant studied philosophy, mathematics, and theology at the University of Königsberg, and began his career as a private tutor. In 1755 he received his *habilitation* (higher doctorate) from Königsberg, where he became a lecturer and later, in 1770, professor of logic and metaphysics. One of the founders of classical German philosophy, Kant had an enduring influence on the development of European philosophy from Johann Fichte to **Georg Hegel** and Karl Marx. His most famous works are his "Critiques": *Critique of Pure Reason* (1781), *Critique of Practical Reason* (1788), and *Critique of Judgment* (1790).

Kant was concerned with scientific problems well into his old age. The most interesting of his writings for astronomy, however, are those he composed up to 1755: on "The True Estimation of Living Forces," on "Whether the Rotation of the Earth Has Undergone Change over Time," on "Whether the Earth Is Growing Old," and finally, the *Universal Natural History and Theory of the Heavens: Or Essay on the Constitution and Mechanical Origin of the Entire Universe, Derived from Newtonian Principles*. Right from the first of these, Kant was beginning to work out his "dynamic" view of nature. This view developed further into his ideas on the opposition of contrary forces and also, since it posited a fundamental bond between matter and motion, contradicted some of the theological conceptions of 18th-century theism.

The earliest application of these ideas led Kant to consider the dynamic interrelationship within the Earth–Moon system. In particular, the Earth's spheroidal shape pointed to the conclusion that before it rose out of "chaos," Earth had existed in a fluid state. Development and decline are a natural process. From the start, accordingly, Kant was concerned about explaining the Earth in terms of not only its being, but its becoming.

In order to determine the origin and evolution of the planetary system as presented in the *Universal Natural History*, Kant first considered its structure. The stability of the system is ensured by means of the critical opposition of gravitation and centrifugal force – a claim that indicates what Kant means by the phrase in his subtitle *derived from Newtonian Principles*. And determining the structure of the planetary system offered in turn the possibility of addressing its history.

Thus, like **Georges Leclerc**, (Comte de Buffon) Kant proceeded by deriving a system's development from its structure, on the theory that a common cause must have given rise to these phenomena. According to Kant, the path of development inscribed in these structures began in a state in which the primal matter of Sun, Moon, planets, *etc.* was so dispersed that it filled the entire universal space. But because matter itself is active, the cosmic state of rest lasted only momentarily. The elements have the inherent capacity to set each other in motion; they are their own source of life. Matter itself instantly strives to evolve. The dispersed elements of a denser sort, by means of attractive force effective spherically about them, draw to themselves all matter of lesser specific gravity. In this process, according to Kant, the repulsive force prevents a complete implosion. Thus, in the center of this cloud there forms an aggregation of matter, from which the Sun came into existence. Other particles of matter striving toward the center collided with each other and, so diverted into other paths, formed the planets and (by an extension of the same process) the planetary satellites. Kant's postulating such long stretches of development not only contradicted his readers' conceptions of biblical creation, but also entailed "a process spanning millions of years and centuries, before the developed state of nature in which we find ourselves achieved the perfection it has now arrived at." Indeed, Kant presumes that the process whereby the worlds came into being is still carrying on, for many of the heavenly bodies have not yet arrived at their states of perfection.

In addition, Kant applied the Solar System's principles of origin to the sidereal realm, asserting that the stars are nothing but "suns and centers of similar systems." Thus, he succeeded in drawing a connection between the Solar System and the stars, which led still further outward to the Milky Way. This Kant explained as a disk-like, lens-shaped cluster of stars, with individual stars concentrated along the plane of the galactic equator – analogous to the Solar System. This proposal had already been put forward by **Thomas Wright** in 1750, and Kant himself identifies Wright's work, which likewise rests upon Newtonian physics, as having powerfully inspired a number of his ideas. However, Kant took one step further out into the cosmos, postulating a similarity between our stellar system and other such cosmic structures, namely, the nebulae. In this manner, "the entire universe, the totality of nature," presents itself "as a single system held together by the forces of attraction and repulsion."

Kant was aware of the broad significance of his proposed natural history of objects and systems in the cosmos. He posited his ideas in contradistinction to those of **Isaac Newton**, who "claimed that the hand of God has established this order directly, without the application of the forces of nature." In opposition, Kant self-confidently declares:"I relish the enjoyment, unaided by arbitrary fictions, of seeing a well-ordered Totality producing itself under the direction of thoroughgoing laws of motion – a Totality so resembling the one we now behold that I cannot help but prefer it to those fictions." Expressed in these words is a novel religious conception, the new theology of Deism, in whose framework the influence of a personal God upon the unfolding of the world is considered superfluous and inoperative, with God being granted merely the function of first mover of the laws of nature.

In an appendix to the *Universal Natural History* Kant dealt extensively with the much-discussed question concerning other inhabited worlds. Kant views the origin of life as a product of the evolution of the heavenly bodies themselves, not as an independent act of creation or as a secondary phenomenon. Nevertheless, he also recognized that life is bound up with particular external conditions that do not obtain everywhere nor at all times. Life forms on other planets would develop in a manner corresponding to whatever conditions prevail there, especially as these relate to a planet's distance from the sun, the period of its rotation, and so on. Accordingly, there could be life forms whose state of development far exceeds, or has not yet reached, the level of humankind.

Kant knew that he lacked decisive proof for his proposal concerning cosmic evolution. On the other hand, his work demonstrates what results a paucity of empirical data, combined with fruitful intuition, can achieve: results that precede strict scientific proof by decades. So at first, Kant's theory remained just a scientific hypothesis, which nevertheless attracted great attention from astronomers, particularly at the end of the 18th century. In the period around 1800, the research of **Pierre de Laplace** and **William Herschel** strongly reinforced this reception. About 1870, **Friedrich Zöllner**, among others, drew assistance from Kant in the working out of his astrophysically based theory concerning the evolution of the heavenly bodies.

Jürgen Hamel
Translated by: *Dennis Danielson*

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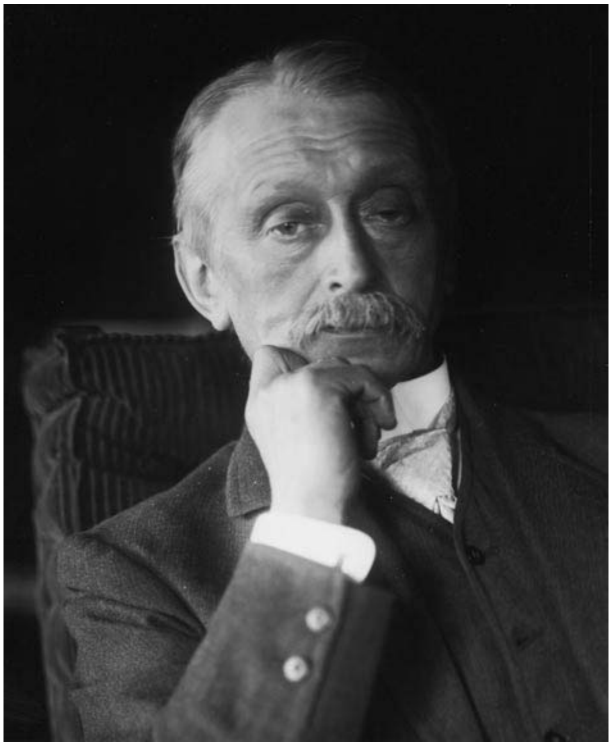
Kapteyn, Jacobus Cornelius

Born **Barneveld, the Netherlands, 19 January 1851**
Died **Amsterdam, the Netherlands, 18 June 1922**



Dutch astronomer Jacobus Kapteyn made his most important contributions to the study of stellar statistics, *i. e.*, the determination of the numbers and types of stars in different parts of space and their motions. His name is attached to the Kapteyn selected areas (particular directions in the sky that are informative for studying stellar statistics) and to the so called Kapteyn universe (his reconstruction of the stellar distribution, which put the Sun very near the center of a rather small Galaxy). The former are still used.

Kapteyn was the son of Gerrit J. and Elisabeth C. (*née* Koomans) Kapteyn, who conducted a school for boys. Jacobus married Catharina Elise Kalshoven. They had a son and two daughters, one of whom married **Ejnar Hertzsprung**. At the age of 16, Kapteyn passed the entrance examination for the University of Utrecht. There he studied mathematics and physics, receiving a Ph.D. (*magna cum laude*) in 1875 with a thesis on the vibration of a membrane.

Kapteyn accepted a staff position at Leiden Observatory in 1875. As a result he made astronomy a career; he was appointed in 1878 to the newly instituted professorship of astronomy and theoretical mechanics at the University of Groningen. Kapteyn created, and became director of, the Astronomical Laboratory at Groningen in 1896 and held both positions until his retirement in 1921.

Kapteyn's major contributions were in the domain of galactic research. His work presented the first major step after those of **William** and **John Herschel**. At the time that Kapteyn initiated his ambitious, systematic program, the execution of which would become his life's work, the problem of the space distribution of the stars was still tantamount to the problem of the structure of the Universe. It was not known yet that the Galaxy was only one of the countless stellar systems that populate the Universe. Milestones in Kapteyn's research were the discovery, in 1904, of the so called star streams, the determination of the stellar luminosity function, the study of isolated, loose groups of massive, hot B-stars, and the model of the Galaxy presented in his article "First Attempt at a Theory of the Arrangement and Motion of the Sidereal System" (published in the *Astrophysical Journal* of May 1922).

Even before he made his discovery of the star streams, Kapteyn had accomplished a major reference work known as the *Cape Photographic Durchmusterung* [CPD] in collaboration with **David Gill**, director of the Royal Observatory in Cape Town, South Africa. Since the University of Groningen (in spite of Kapteyn's request) could not provide him with a telescope, he offered to Gill to undertake at Croningen the measurement of stellar positions on photographic plates taken by Gill. Their purpose was to provide for the southern sky the data on stellar positions and brightness, which for the northern sky had been measured by visual – not photographic – means several decades earlier by **Friedrich Argelander** at Bonn Observatory and known as the *Bonner Durchmusterung*. For these measurements Kapteyn devised an unconventional method using a theodolite, thus obtaining equatorial coordinates directly and skipping the intermediate phase of rectangular coordinates. The CPD, published in three volumes in the years 1896–1900 after 13 years of collaboration, contains 454,875 stars between the South Celestial Pole and the declination −18°. This project may be regarded as the first step toward the establishment of Kapteyn's unique astronomical laboratory that soon would gain international fame.

As a first step in the estimation of the distances of the stars, a conventional method used the stars' proper motions, *i. e.*, their displacements on the sky. A large proper motion is a strong indicator of proximity of the star to the Earth, small proper motions generally indicate remoteness. Kapteyn applied this method using improved proper motions partly measured at his laboratory. This led to a major discovery: It had been assumed, more or less tacitly, by earlier investigators that stellar motions are similar to molecular motions in that they show no preferential direction. Kapteyn discovered that this is not so: A preferential direction exists which he interpreted as evidence for relative motion between two intermingled stellar populations. The full understanding of this phenomenon came in the 1920s in the context of the dynamical theory of the notation of the Galaxy.

For the exploration of the structure and dimensions of the Galaxy, Kapteyn devised statistical methods using large numbers of stars with known apparent magnitudes, colors, proper motions, and trigonometric parallaxes. In order to arrive at an unbiased yet sufficiently limited sample, he proposed a scheme called *The Plan of Selected Areas*, according to which these data would be assembled for all stars within the limits of observation in 206 small areas evenly distributed on the sky. The proposal met with considerable response, so that eventually 43 observatories collaborated in one way or another. After Kapteyn's death, Commission 32 of the International Astronomical Union was created for the supervision and extension of the project.

Kapteyn's ultimate aim was the determination of the stellar density distribution in the Galaxy. Observational data required were the numbers of stars at different apparent magnitudes in different directions, combined with the distribution of their proper motions. The approach was essentially numerical; no model was presupposed. An important intermediate quantity to be determined was the "Luminosity Function", which describes the distribution of the intrinsic luminosities of the stars contained within a given volume of space. It has proven to be a most important piece of information for the study of the so called Initial Luminosity Function, the distribution of stellar luminosities, and hence of stellar masses—at the time of their birth. According to Kapteyn's model, arrived at around the year 1921, the Galaxy showed a disk-like structure with the Sun located close to the center. Its greatest extension was in the direction of the Milky Way (about 30,000 light years). Its smallest dimension (about 5,000 light years) was in the directions of the galactic poles. The latter result, which might be called the "thickness" of the Galaxy, has been confirmed and refined by later authors including Kapteyn's pupil **Jan Oort**. However, Kapteyn's results for the position of the Sun and the extent of the system in the directions perpendicular to the pole have been found to be spurious because he neglected the absorption of light by interstellar matter. Kapteyn was aware of the problem of the possible existence of such matter, and vigorously pursued methods to identify it through its reddening effect on the colors of distant stars but without conclusive results.

Kapteyn received numerous honors from scientific societies and universities all over the world. He was a celebrated lecturer to audiences of all kinds.

At the invitation of **George Hale**, founder of the Mount Wilson Observatory, Kapteyn paid annual visits of several months duration to Mount Wilson until these were interrupted by World War I. He firmly believed it to be the duty of scientists to bridge gaps caused by political developments and was deeply shocked when, upon termination of the war, the Central Powers were excluded from newly created international organizations.

The archives of the Kapteyn Institute of Groningen University contain notebooks used by Kapteyn in the years 1907–1922, in which he jotted down quick calculations and drafts for articles and letters. Also kept here are copies of the correspondence of Kapteyn with leading astronomers all over the world.

Adriaan Blaauw

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Kāshī: Ghiyāth (al-Milla wa-) al-Dīn Jamshīd ibn Masʿūd ibn Maḥmūd al-Kāshī [al-Kāshānī]

Died **Samarqand, (Uzbekistan), possibly 22 June 1429**

Kāshī was one of the most accomplished and prolific scientists at the Samarqand Observatory, which itself was one of the preeminent scientific institutions of the 15th century. Kāshī was born in Kāshān in northern Iran and had long worked on astronomical problems before finding a patron. Despite being a physician (as he mentions at the end of his *Risāla dar sharḥ-i ālāt-i raṣd*), he tells us in his *Zīj* that he had lived in poverty in various cities of central Iran, mostly in his hometown. Kāshī first found patronage in Herat at the court of Shāh Rukh, son of Tīmūr and father of **Ulugh Beg**. On 2 June 1406 Kāshī was back in Kāshān, where he witnessed an eclipse of the Moon, as he did also in 1407 as well as in 1416 at which time he presented his book the *Nuzha*. Presumably between 1417 and 1419 Kāshī was invited to Samarqand by Ulugh Beg. It was most likely in 1420 that he made the long journey north to Samarqand, where he joined the scientific circle at the residence of the prince. Under Ulugh Beg's sponsorship, Kāshī finally obtained a secure and honorable position, becoming the prince's closest collaborator and consultant. In the introduction of Ulugh Beg's *Zīj* (astronomical handbook with tables), Kāshī is singled out for praise. When the observatory was founded in 1420, Kāshī took part in its construction, organization, and provision, as well as in the preparation of Ulugh Beg's *Zīj*. During this time, he traveled with the royal retinue to Bukhārā, as he mentions in the letters to his father. Kāshī, the most prominent of the scholars associated with Ulugh Beg's learned staff, spent the rest of his life as a distinguished scientist in Samarqand, where he died, leaving incomplete the observations required for Ulugh Beg's *Zīj*.

Although Kāshī wrote a number of important mathematical treatises, we will here be concerned only with his astronomical works. It is worth mentioning, though, that he was a remarkable computational mathematician whose calculations of sin 1° (correct to 18 decimal places) and π (correct to 16 decimal places) were to remain unsurpassed for some time.

Probably while living in Kāshān, Kāshī wrote two minor astronomical treatises. The first, entitled either the *Sullam al-samāʾ* or the *Risāla kamāliyya*, dealt with the sizes and distances of the celestial bodies. Completed on 1 March 1407, it is dedicated to a vizier named Kamāl al-Dīn Maḥmūd and is preserved in several copies. The second is the *Mukhtaṣar dar ʿilm-i hayʾat*, a compendium on astronomy written in 1410/1411 for a certain Sultan Iskandar, probably a nephew of Shāh Rukh and a cousin of Ulugh Beg; it is preserved in two Persian manuscripts in London and Yazd.

In 1413/1414 Kāshī completed his *Zīj-i Khāqānī*, which was either dedicated to Shāh Rukh, for Kāshī was staying in Herat in this time, or to Ulugh Beg, for he says in the *Zīj-i Khāqānī* that he would not have been able to finish his work without the support of the prince. Kāshī's *Zīj*, preserved in several Persian copies, is organized in six treatises and starts with an introduction in which Kāshī pays respect to **Naṣīr al-Dīn al-Ṭūsī**, but expresses his dissatisfaction with much of Ṭūsī's *Īlkhānī Zīj*, which Kāshī proposes to correct. The first treatise of Kāshī's *Zīj* contains the chronological section with a description of the common calendars in use; the second the mathematical section with a presentation of the standard trigonometric and astronomical functions; the third and fourth the spherical astronomy section with procedures and solutions of problems in spherical astronomy including tables; the fifth different solutions for the determination of the ascendant; and the sixth astrological material. Each treatise includes an introduction with a glossary of technical terms, and two chapters with solutions, computations, and proofs. The tables computed by Kāshī use pure sexagesimals; the sine tables give four sexagesimal places for each minute of arc. Kāshī also mentions some observational instruments such as the mural quadrant and the revolving parallactic ruler, seemingly the "perfect instrument" of **ʿUrḍī**.

In January 1416, presumably in Kāshān, Kāshī composed by order of Sultan Iskandar, possibly the Qarā-Qoyunlu king, the *Risāla dar sharḥ-i ālāt-i raṣd*, a commentary on observational instruments, preserved in two Persian manuscripts in Leiden and Tehran. Most of the instruments described by Kāshī are mentioned by **Ptolemy**, and/or listed in ʿUrḍī, such as the parallactic ruler for the measurement of zenith distances, an armillary sphere as well as an equinoctial, and a solstitial armilla. Further, he describes the Fakhrī sextant, used for the measurement of the altitude of stars. This instrument, invented by **Khujandī** about 1000 in Rayy, was also described by **Marrākushī** and confirmed by **Bīrūnī**. Kāshī's treatise demonstrates clearly that he had some knowledge on the observatory in Marāgha. His work represents a connecting link between these two great centers of medieval astronomical activity, centers whose influence reached at least as far as Istanbul to the west, and China and India to the east, if not to the earliest European observatories.

In the *Nuzhat al-ḥadā'iq* Kāshī describes two instruments that he invented, the "plate of heavens" and the "plate of conjunctions." The first version of this text was finished in Kāshān on 10 February 1416, which is preserved in an Arabic manuscript in London. The second version was revised in Samarqand in June 1426. It is only known in a lithographic edition of some of Kāshī's works, printed in Tehran 1888/1889. The "plate of heavens" is a planetary equatorium, a computing instrument to find the true position of a planet, an alternative to lengthy numerical computations by means of reducing an essentially three-dimensional problem to a succession of two-dimensional operations. Kāshī's "plate of heavens" is the only example recovered from the lands of eastern Islam, and moreover, the most compact, which includes a method for the determination of planetary longitudes as well as latitudes. His "plate of conjunctions" is a simple device for performing linear interpolation, a mechanical application of elementary geometry, for ascertaining the time of day at which expected planetary conjunctions will occur.

Besides these works, Kāshī wrote numerous minor astronomical treatises. In his *Taʿrīb al-zīj*, preserved in Leiden and Tashkent, he translated the introduction of Ulugh Beg's *Zīj* from Persian into Arabic, the translation being completed during Kāshī's lifetime. Further, he wrote the *Miftāḥ al-asbāb fī ʿilm al-zīj* (The key of the causes in the science of astronomical tables), extant in an Arabic manuscript in Mosul; the *Risāla dar sakht-i asṭurlāb*, on the construction of the astrolabe, extant in a Persian manuscript in Meshed; and the *Risāla fī maʿrifat samt al-qibla min dā'ira hindiyya maʿrūfa*, on the determination of the *qibla* by means of the "Indian circle," extant in an Arabic manuscript in Meshed. The *Zīj al-tashīlāt*, which Kāshī mentions in his *Miftāḥ al-ḥisāb*, seems not to be extant. The alleged *al-Risāla al-iqlīlāmina* (mentioned by Kennedy in *Planetary Equatorium*, p. 7) is a misattribution based on a misreading.

Though they are not astronomical treatises, two letters that Kāshī sent from Samarqand to his father in Kāshān are nonetheless very informative. The first of them, preserved in Tehran, was written about 1423. Because Kāshī believed it was lost, sometime after the first letter he composed a second, which contains descriptions similar to that in the first, but also includes some new information. It is preserved in three Persian manuscripts in Tehran. Both letters describe Ulugh Beg as a generous and learned man. Kāshī praises his erudition and mathematical capacity, and gives a picture of the prince as a scientist among those brought together and patronized by him. The observatory was founded as Kāshī had suggested, quite similar to the earlier observatory in Marāgha. Its building was aligned in the meridian on the top of a rock, in which parts of the Fakhrī sextant are carved, with a flat roof for the placing of further instruments. Kāshī mentions several instruments constructed for the observatory, some of them listed in his commentary on observational instruments as well. Further, Kāshī describes a sundial at an inclined wall, a device for the determination of the afternoon prayer, and a *zarqāla*, a universal astrolabe invented by **Zarqālī** in 11th-century Andalusia. Kāshī had a very positive image of himself and told his father that he knew how to solve problems others could not. On his father's advise, he was completely engaged in working at the observatory, but this left him little time to do anything else.

Kāshī was unaffected by the newer planetary theories of the "School of Marāgha," but his improvement and correction of the *Īlkhānī Zīj* of Naṣīr al-Dīn al-Ṭūsī is of remarkable accuracy. In the letters to his father, Kāshī gives a unique glimpse into the court of Ulugh Beg and the observatory at Samarqand, as well as into the work and life of a medieval astronomer.

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Kauffman, Nicolaus

Born **possibly (Schleswig-Holstein, Germany), 1619**
Died **Paris, France, 14 January 1687**

Usually remembered for his work on navigation, Nicolaus Mercator, primarily a mathematician and astronomer, is *not* the Mercator for whom the map projection is named (**Gerardus Mercator**). He was born Nicolaus Kauffman to Martin Kauffman, a schoolmaster at Oldenburg in Holstein. No information is available about Mercator's mother or why he changed his name. Although his father worked in Holstein, there is no evidence confirming Mercator's birth there; some evidence points to Denmark as his birthplace. Raised Lutheran, which speaks of his youth in Germany, Mercator spent much of his career in England and later died in France. It is most likely that Mercator began work at his father's school. In 1632 he graduated from the University of Rostock and received an M.Phil. from the same institution in 1641. He also spent time studying at the University of Leiden. Mercator joined the philosophy faculty at Rostock in 1642. From 1648 to 1654 he worked at the University of Copenhagen, but was forced to leave when the university closed due to the plague. In 1660 he began work as a tutor in mathematics in London. It is possible (though not known for certain) that Oliver Cromwell invited Mercator to London as Cromwell knew of Mercator's 1653 tract on calendars. The period of 1682–1687 found Mercator working in France where he had been commissioned to plan the waterworks at Versailles.

Mercator was keenly interested in astrology as were many astronomers of his time. While at Copenhagen he published several textbooks in what was arguably his most prolific period. The year 1651 saw no fewer than three books published: *Trigonometria sphaericorum logarithmica* (dealt with spherical trigonometry), *Cosmographia* (dealt with geography and marked the beginning of his work in navigation), and *Astronomica* (his first contribution to astronomy). Two years later he published a book on mathematics, *Rationes mathematicae*. Two works dealing with astronomy, *Hypothesis astronomia nova* (1664) and *Institutiones astronomicae* (1676), appeared while he was living in England. The former combined **Johannes Kepler**'s ellipses with Mercator's own work. The latter was a general exposition of contemporary astronomical theory. He corresponded with **Isaac Newton** regarding lunar theory and developed a new method to determine the line of apsides of a planetary orbit, challenging **Jean Cassini**'s work in this area.

It was also during his time in England that one of Mercator's most important works appeared. *Logarithmotechnia* (1668) contained constructions of logarithms from first principles. Combining this with a particular inequality he was able to establish a series expansion that now bears his name. He was the first to calculate, by means of an infinite series, the area connected with a hyperbola (something Newton also did, but published later). This, of course, was not just a watershed in the foundations of calculus, but also had a tremendous subsequent impact on celestial mechanics.

In addition to his theoretical work Mercator made several practical contributions to science. His marine chronometer won him fellowship in the Royal Society in 1666. In 1669 he improved upon his previous clock designs and developed an efficient method for sailing into the wind.

Ian T. Durham

Alternate name

Mercator, Nicolaus

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Keckermann, Bartholomew

Born **Danzig, (Gdańsk, Poland), 1571 or 1573**
Died **Danzig, (Gdańsk, Poland), 25 July 1609**

Bartholomew Keckermann developed a system of astronomy that was a basic outline of the Aristotelian universe, and which was widely used as a textbook.

Born to Calvinists George and Gertrude Keckermann, Keckermann studied under **Jacob Fabricius** at the Academic Gymnasium of Danzig starting in 1586, before moving to Wittenberg, where he enrolled at the University of Wittenberg in 1590. In 1592, Keckermann enrolled at the University of Leipzig, but after one semester he and fellow Calvinist students became unwelcome due to the death of protector Prince Christian I. Keckermann then moved to Heidelberg, where he studied from 1592 until 27 February 1595, receiving a master of arts degree. Keckermann stayed in Heidelberg and eventually held a professorship in Hebrew there, but in 1602 after writing to the Danzig City Senate about his desire to return to his native city, he was offered a position to teach philosophy in the Danzig Gymnasium. There, Keckermann worked incessantly, paying little attention to sleep or health. This led to his early death.

Known as a great pedagogue, Keckermann employed a systematic method of introducing students to subjects such as geometry, astronomy, optics, and geography. Keckermann presented his system of astronomy during lectures in 1605 and 1607. This system was first published posthumously in the *Systema physicum, septem libris* (1610), and later in different forms in the *Systema astronomiae compendosium* (1611), his *Operum omnium quae extant* (1614), and the *Systema compendiosum totius mathematices* (1617). Included in some of these works were discussions of phenomena related to astronomy such as comets and meteors, but they were placed under different systems such as physics. The commentaries of **Georg Peurbach** and **Johann Müller** (Regiomontanus) aided Keckermann in developing his system of astronomy.

Keckermann began with general information about the motions of the heavenly spheres, which he held to be material despite arguments against this position resulting from observations of the comet of 1577 showing that it traversed planetary spheres. He then treated the motions of each of the planetary spheres separately. After working through the planetary spheres, Keckermann ended his system of astronomy by giving fundamental explanations concerning time reckoning and the reasons behind the recent change from the Julian to the Gregorian calendar.

Keckermann's syntheses of astronomical knowledge in his lectures and in the posthumous publications of his textbooks were widely used as school texts. At Harvard, Adrian Heereboord recommended Keckermann's work as the best system of Aristotelian physics. At early 17th-century Cambridge, Keckermann's works were used as standard manuals in undergraduate instruction. The English author **John Milton** was among the Cambridge students who were probably influenced by Keckermann's synthesis of natural philosophy.

However, it is safe to say that Keckermann's works were not used for their originality. He believed that tradition should prevail over unsubstantiated claims. By placing knowledge that was "rightly-ordered" before knowledge that may in fact be "true," Keckermann stuck with the wisdom of the ancients over the moderns. For example, although he was favorable to those who denied the reality of solid celestial spheres, he could not accept their claims "because as yet no astronomical precepts have been established, through which an opinion and hypothesis of this sort can be taught in the schools." He was waiting for the day when such precepts would be advanced through foundational textbooks such as his own. Because of his attitude, Keckermann had mixed reactions toward the work of recent astronomers like **Nicolaus Copernicus** and **Tycho Brahe**. In the margins of his personal copy of Copernicus's *De Revolutionibus* he acknowledged and even praised Copernicus and other modern astronomers like **Rheticus**, **Caspar Peucer**, and Brahe. However, his system of astronomy in the *Systema compendiosum* followed the traditional Aristotelian model with only short references to the works of Copernicus and Brahe.

Theologically, Keckermann believed that there was a harmonious relationship between God and nature. A knowledge of physics was necessary in order to understand the scriptural accounts of creation and of natural things in the Bible such as gems, metals, and foods. His view of comets also had a theological flavor. Although he took a standard astrological position when he said that comets portend events on the Earth such as changes in empires, his causal account of why this is the case became theological. Keckermann claimed that good angels or bad demons worked with the matter of a comet to produce effects on the Earth.

The breadth of Keckermann's work is amazing, considering how long he actually lived to create it. This probably resulted from his attitude not to be satisfied with leaving questions unanswered and at least attempting a "most probable" explanation to difficult questions.

Derek Jensen

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Keeler, James Edward

Born **La Salle, Illinois, USA, 10 September 1857**
Died **San Francisco, California, USA, 12 August 1900**

In an era dominated by large refracting telescopes, James Keeler demonstrated the promise and future prospects of reflecting telescopes for conducting astronomical research. His celestial photographs taken with the Crossley reflector demonstrated conclusively

that the nebulae, many of them spiral nebulae, existed in much larger numbers than had been previously imagined. Keeler used the spectrograph to measure fundamental physical and chemical properties of celestial objects as a pioneer astrophysicist.

Keeler was the son of William F. and Anna (*née* Dutton) Keeler. His father, a senior partner in the La Salle Iron Works, had previously been a watchmaker and traveled around the world, after having no success in the California Gold Rush. Keeler grew up in La Salle, Illinois, where he witnessed the total solar eclipse that swept across the United States on 7 August 1869. That event seemingly left a strong impression on Keeler. In November of that year, his family relocated to Mayport, Florida, a move that ended Keeler's chances for a secondary education.

Keeler developed his interest in astronomy from the practical side of surveying, a skill that he learned from his father. He ordered a 2-in. achromatic lens, and two smaller lenses for eyepieces, from a Philadelphia optical house. Within a week of their arrival Keeler assembled a telescope. In addition to viewing terrestrial objects he observed the Moon, Jupiter, Saturn, nebulae, and other celestial objects. Keeler's sister, Lizzie, attended a private school in Tarrytown, New York. When she and her classmates observed Saturn through a telescope owned by a local amateur astronomer and philanthropist, Charles H. Rockwell (1826–1904), Lizzie mentioned that she had seen the planet through her brother's homemade telescope in Florida. Intrigued, Rockwell took it upon himself to finance Keeler's collegiate education. Keeler further impressed Rockwell by paying for his own passage northward, by assisting his schooner's captain with celestial navigation.

Rockwell enabled Keeler to gain admittance to the second freshman class at Johns Hopkins University in Baltimore, in December 1877. During his college years, he assisted a research team that viewed the total solar eclipse of 29 July 1878 from Central City, Colorado. Keeler sketched the solar corona with the aid of a 2-in. aperture telescope. This drawing, along with his first scientific paper, was published in the United States Naval Observatory's report on the eclipse.

After graduating in 1881, Keeler worked as an assistant to **Samuel Langley**, director of the Allegheny Observatory near Pittsburgh, Pennsylvania. Langley was then perfecting the bolometer, an instrument used to measure total energy, including infrared energy from celestial objects. Keeler and Langley explored this hitherto unknown region of the solar spectrum. Keeler then spent a year of postgraduate study abroad, learning physics under Georg H. Quincke at the University of Heidelberg, and under **Hermann von Helmholtz** at the University of Berlin. In 1886, he settled at Mount Hamilton, California, site of the new Lick Observatory (then under construction). Keeler spent the next 7 years as a Lick Observatory astronomer, assisting director **Edward Holden**.

Keeler became one of the pioneers in utilizing spectroscopy to study the composition, temperature, and radial velocities of stars, nebulae, and other celestial objects. His peers considered him to be the leading astronomical spectroscopist of his generation. Along with Langley and several others, he was one of the founders of the new science of astrophysics.

After the 36-in. refractor went into operation at the Lick Observatory in 1888, Keeler used the telescope to measure the wavelengths of emission lines seen in the spectra of nebulae. He went on to demonstrate conclusively that the lines, dubbed *nebulium*, were not emitted by any known chemical element examined under conditions duplicated in terrestrial laboratories. It took another 30 years before Mount Wilson Observatory astronomer **Ira Bowen** identified them as the so-called *forbidden lines* of ionized oxygen, produced under extremely low-density conditions.

In 1891, Keeler married Cora Slocomb Matthews, a niece of the board president of the Lick Observatory trustees. That same year, he accepted an appointment as director of the Allegheny Observatory, after Langley was chosen secretary (director) of the Smithsonian Institution, Washington, District of Columbia.

At Allegheny, Keeler demonstrated that the rings of Saturn are made of individual particles, each traveling with its own orbital velocity around the planet. Using a spectrograph of his own design, and exploiting the principle of the Doppler effect, Keeler measured the speeds of revolution of the ring particles as a function of their distance from the planet. He thus verified the result predicted mathematically by Scottish physicist **James Maxwell** in 1857. Keeler's confirmation of Maxwell's hypothesis was published in the first volume of the *Astrophysical Journal* (1895) and helped him to garner the Rumford Medal of the American Academy of Arts and Sciences.

At the dedication ceremony of the Yerkes Observatory (21 October 1897), Keeler delivered the main invited address, entitled "The Importance of Astrophysics, and the Relation of Astrophysics to Other Physical Sciences." This lecture highlighted Keeler's standing within the American astronomical community and symbolized the growing importance of his subject matter to 20th-century research practices.

Keeler returned to direct the Lick Observatory in 1898 (succeeding Holden), and refurbished its 36-in. Crossley reflector. With that telescope, Keeler obtained the finest photographs to date of the spiral nebulae, which we know today as distant galaxies. Keeler's study of the nebulae, which was continued after his death by Lick astronomer **Heber Curtis** and Mount Wilson astronomer **Edwin Hubble**, gradually led toward an acceptance of these objects as island universes of stars, lying far beyond the Milky Way.

Along with **George Hale**, Keeler founded the *Astrophysical Journal* in 1895, to foster communications among the adherents of what Langley had termed the New Astronomy. He likewise inaugurated the first regular graduate program at the University of California, built around Lick Observatory fellowships, to produce theoretically trained but observationally oriented researchers in astrophysics. Keeler was awarded an honorary Sc.D. by the University of California in 1893, was a recipient of the Henry Draper Medal of the National Academy of Sciences (1899), and was elected to its membership in 1900. That same year, however, he suffered a fatal stroke.

Glenn A. Walsh

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Keenan, Philip Childs

Born **Bellevue, Pennsylvania, USA, 31 March 1908**
Died **Columbus, Ohio, USA, 20 April 2000**

American spectroscopist Philip Keenan was the first "K" of MKK spectral types (where M = **William Morgan** and the second K = Edith Kellman), one of the primary ways of classifying stars from 1943 down to the present. The elder son of Charles Gaskell Keenan and Eveylyn Larrabee (*née* Childs) Keenan, he was discovered by the Stanford University psychologist Lewis M. Terman, after the family moved to Ojai, in central California. Terman included him in a sample of about 1,000 children with high intelligence quotients (above 135), and other indications of exceptional brilliance, whom he followed for many decades, showing that Keenan was quite typical of the group in outstanding later achievements.

Keenan received his BS from the University of Arizona in 1929, publishing his first paper (on the color of the Moon during total eclipse, important for understanding transmission of light by the Earth's atmosphere) the same year. He earned an MA in 1930 and headed east to the University of Chicago and Yerkes Observatory. After initial work with **Edwin Frost**, he completed a Ph.D. in 1932, defending a dissertation titled "An Astrophysical Study of the Solar Chromosphere," working with **Otto Struve** and **Christian Elvey**. Keenan was the 15th Chicago Ph.D. in astronomy, following Morgan who had received his degree a year earlier.

Apart from a year (1935/1936) as an instructor at Perkins Observatory, Keenan remained on the Yerkes and Chicago staff until 1942, observing extensively at the new McDonald Observatory as well as at Yerkes. Following war work (1942–1946) at the Bureau of Ordnance of the United States Department of the Navy, he was appointed to an assistant professorship at the Ohio State University, moving up to a full professorship and acting directorship of the observatory (1955–1957). He retired as professor emeritus in 1976. His last paper was published in 1999, 70 years after his first, setting a record for duration of publications in major American journals.

During the Yerkes years, Keenan was among the first to try to understand systematic errors in measurements of the surface brightnesses of galaxies (an essential sort of data if they are to be used as cosmological probes) and, with **Louis Henyey**, Keenan attempted to account for the radio emission from the plane of the Milky Way that had been detected by **Karl Jansky** and **Grote Reber**. They concluded in 1940 that it could not be ordinary thermal emission from ionized hydrogen, but were unable to say what it was; a similar conclusion was drawn by **Jesse Greenstein** and **Fred Whipple** working at Harvard. Keenan also worked on interpretation of a number of solar phenomena, including prominences, granulation, limb darkening, and the chromosphere.

About 1939, Morgan and Keenan began their collaboration to develop a two-dimensional system of stellar classification that would have signatures for both the surface temperatures of stars (like the old OBAFGKM system of **Annie Cannon**) and their luminosities (like the "c-characteristic" of **Antonia Maury**). They succeeded in this so well that the resulting system, enshrined in the 1943 publication *An Atlas of Stellar Spectra, with an Outline of Spectral Classification* by Morgan, Keenan, and Kellman, remains standard today in an updated version published by Morgan and Keenan [MK] in 1973. On the whole, Morgan specialized in hot stars and Keenan in cool ones, and the system was pushed to more extreme types in both directions in later years. Jason Nassau was a frequent collaborator on luminosity indicators (such as the line of neutral calcium and some molecular bands) for cool stars. The original MKK *Atlas* actually included some stars (types R, N, and S) of unusual chemical composition, and Keenan later developed temperature indicators for these as well.

Although both Morgan and Keenan were firm about the need to understand the physical processes underlying spectral types, Keenan particularly remained focused on the process: The proper way to classify stars was to start by obtaining spectra of a number of standard stars with the telescope, spectrograph, and detector you proposed to use, and then go on to the program stars, classifying them by comparison with those locally prepared standards, before attempting to derive numbers for temperature, luminosity, or composition. Using this approach, one could accurately classify spectra even at very low dispersion, a whole star represented by only a few millimeters of exposed photographic emulsion.

Keenan received a honorary doctorate from the University of Cordoba in 1971, and remained active in several professional societies long past retirement. Nevertheless, he resigned his membership in the American Astronomical Society in the 1970s over some issue now long forgotten. At a 1993 conference commemorating the 50th anniversary of the *Atlas*, the Vatican Observatory presented him with a medal honoring his pioneering work in spectral classification. Keenan was fluent in Spanish; fond of literature, music, and cooking; and an enthusiastic gardener, stamp collector, and player of bridge and tennis. He never married; his most important survivors were his students.

Mary Woods Scott

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Keill, John

Born **Edinburgh, Scotland, 1 December 1671**
Died **Oxford, England, 31 August 1721**

From his seat as Savillian Professor of Astronomy at Oxford University, John Keill helped popularize **William Whiston**'s theory that the biblical Universal deluge resulted from a comet striking the Earth.

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Kempf, Paul Friedrich Ferdinand

Born **Berlin, (Germany), 3 June 1856**
Died **Potsdam, Germany, 16 February 1920**

As a solar spectroscopist, Paul Kempf helped establish the reputation of the new Potsdam Astrophysical Observatory with his accurate measurements of spectral line wavelengths and the rotation rate of the Sun and by compiling a major photometric catalog.

Kempf's father, an actuary of the court, died when Paul was young, leaving him and an elder brother to be raised by his mother. Kempf graduated in 1874 from the Gymnasium of the Grauen Kloster in Berlin. Though a student for one semester at Heidelberg, he returned to his native city and pursued astronomy under the tutelage of Wilhelm Foerster and Friedrich Tietjen at the University of Berlin. At the age of 22, Kempf received his Ph.D. in 1878. His thesis, on the Ptolemaic theory of planetary motion, was awarded a prize by the philosophical faculty and subsequently published.

Kempf was then appointed an assistant at the newly established Potsdam Astrophysical Observatory, where he conducted observations of sunspots under the supervision of **Gustav Spörer**. Solar studies became one of Kempf's principal lines of research; he determined the wavelengths of some 300 absorption lines in the solar spectrum (with **Gustav Müller**, 1886) and measured the Sun's rotation from the motions of calcium flocculi (1916).

Kempf and Müller likewise collaborated on the observations and reductions of the Potsdam *Photometrische Durchmusterung des Nördlichen Himmels* (photometric catalogue of the northern heavens, 1894–1906), which compiled the brightnesses and colors of some 14,000 stars down to visual magnitude 7.5. This enormous task was completed using the astrophotometer (and its artificial star) constructed by **Johann Zöllner**. Historian J. B. Hearnshaw has described the Potsdam *Durchmusterung* as one of "[t]hree great photometric catalogues of the late nineteenth century" and, which consistently displayed the smallest probable error of mean magnitude.

Kempf participated in (and later organized) several astronomical expeditions, including that to observe the transit of Venus from Punta Arenas in South America (1882). He traveled twice into the interior of Russia to observe total solar eclipses (in 1887 and 1914). In 1894, he journeyed with Müller to the vicinity of Mount Etna and conducted observations to measure the extinction of starlight by the Earth's atmosphere.

Kempf's contributions may be gauged by his 1915 appointment as secretary to the board of the Astronomische Gesellschaft (Astronomical Society). Simultaneously, he was chosen its treasurer, following Heinrich Bruns's resignation. Kempf brought out a translation of **Simon Newcomb**'s *Popular Astronomy* (1914) and was preparing a revised edition at the time of his death.

Jordan D. Marché, II

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Müller, Gustav, and Paul Kempf (1894–1906). *Photometrische Durchmusterung des Nördlichen Himmels*. Potsdam: Potsdam Publications.
——— (1907). *Photometrische Durchmusterung des Nördlichen Himmels*: *Generalkatalog*. Potsdam: W. Engelmann.

Kepler, Johannes

Born **Weil der Stadt, (Baden-Württemberg, Germany), 27 December 1571**
Died **Regensburg, (Bavaria, Germany), 15 November 1630**

Johannes Kepler revolutionized astronomy and physics even more than **Nicolaus Copernicus**, in as much as he broke with the principle of uniform circular motion for celestial bodies, which Copernicus had tried to uphold. His reasoning was physical, but he created a rigorous mathematical model of planetary kinematics. Although best remembered today for his "three laws of planetary motion," Kepler made contributions to science that were much broader than this simple mnemonic suggests, and his discoveries were hard won.

His father, Heinrich Kepler, was a soldier who later abandoned the family; his mother, Katharina Guldenmann, was the daughter of the *Burgermeister* (mayor) of Eltingen, a village near Weil der Stadt. The family's means were modest. As a scholarship student at the University of Tübingen (1589–1594), Kepler was educated in a rigorous curriculum that had been established by Protestant reformers during the previous half-century, and that helped to develop his understanding of the roles of astronomy and mathematics. Kepler's own confession was Lutheran, with Calvinist leanings. At Tübingen, he fell under the particular influence of the instructor **Michael Mästlin**, a convinced follower of Copernicus who was to remain Kepler's mentor in astronomy for many years. From this time at least, Kepler was a Copernican. He planned a career in divinity, but when a teaching position in mathematics became available at a seminary in Graz in 1594, Kepler's instructors recommended him for the post as the strongest of their candidates. It was in Graz that he developed his first original ideas in astronomy, which he published in the *Mysterium Cosmographicum* in 1596. This work adumbrates the worldview that is the basis of much of his future theoretical work, in that it puts forth a structure of the planetary system based on geometrical regularity. The particular model of the heavens that it lays out determines both the number of the planets and their sequential distances from the Sun by nesting the five classical regular solids within the (notional) spheres encompassing the planetary orbits. Kepler, *i. e.*, created a model with a cube inscribed within the sphere representing the orbit of Saturn, a sphere inscribed within this to represent the orbit of Jupiter, a tetrahedron inscribed within this and a sphere inscribed within the tetrahedron to represent the orbit of Mars, and so forth. By this structure, the proportional distances of the planets from the Sun (as then known from the Copernican model) were approximately represented.

During his tenure in Graz, Kepler was engaged to a twice-married heiress, Barbara Müller, whom he married in 1597. They had three children who survived childhood, but one died in 1611, and Barbara followed a few months later. Kepler married Susanna Reuttinger in Linz in 1613. Three of their six children survived.

The *Mysterium*, which was Kepler's first book, and his correspondence with **Tycho Brahe** (as well as his inadvertent involvement in Brahe's priority dispute with **Nicholaus Bär** [Raimarus Ursus] over the non-Copernican planetary theory according to which the planets orbit the Sun, which in turn orbits the Earth) led Brahe, the preeminent European astronomer, to invite Kepler to join him in Prague at the court of the Holy Roman Emperor Rudolph II in 1600, as one of several mathematical assistants. Kepler, who had greater ambitions for modeling the Universe, was assigned the carefully circumscribed task of determining the parameters of the orbit of Mars from Brahe's meticulous observations.

A few days after Brahe's death in 1601, Rudolph appointed Kepler Imperial Mathematician; he was to be Brahe's successor. This position, at a comparatively early age, brought him European eminence. Several more major works followed during the reign of Rudolph, including the *Astronomiae Pars Optica* in 1604, and the *Astronomia Nova*, based on his work on the orbit of Mars, in 1609. Rudolph was deposed and replaced on the throne by his brother in 1612, and the remainder of Kepler's life was unsettled.

The *Astronomia Nova*, unique among astronomical works to this date in that it is not only a treatise, but also a personal history of scientific discovery subtly reworked to convince the reader of the inevitability of its conclusions, creates a wholly new and revolutionary model of planetary kinematics. The book presents the first two of what (since at least the time of **Joseph de Lalande**, in the late 18th century) have been known as Kepler's "three laws of planetary motion." These two are: (1) that planets move in elliptical orbits with the Sun at a focus and (2) that a line connecting a planet with the Sun will sweep over equal areas in equal periods of time. The first law, in particular, demolished the Western (including the Arabic) tradition of planetary models derived from combinations of circular motions. Kepler actually discovered the second law first, and used it as an aid to calculation. Because the ellipticity of Mars' orbit is very small, Kepler's discovery rested both upon Brahe's extremely precise (nontelescopic) observations and Kepler's own faith in their accuracy. Another noteworthy aspect of the book is that Kepler attempts to derive the kinematics of planetary motion from physical principles that are based in part on the discovery, by **William Gilbert**, that the Earth itself is a magnet. This line of reasoning required that the Sun be at one focus of the planetary orbits. In the Copernican system, though the Sun was at the center in a general sense, it was not actually at the mathematical center of the orbits; Kepler thereby forced classical astronomy to face the physical consequences of the Copernican revolution. One cannot, however, draw a direct line from Kepler's theorizing to the planetary dynamics that were developed later in the 17th century, by **Isaac Newton** in particular.

Kepler's account of his model was persuasive for a number of technically proficient astronomers, but the practical difficulties of using it to calculate planetary positions were considerable. It was some time before his discoveries were widely applied in practice. In particular, the theory required the solution of what has become known as Kepler's equation or Kepler's problem, the best solution to which, if only as a mathematical problem rather than a practical one, has occupied a number of mathematicians over the centuries (and, in different contexts, at least as far back as the 9th century). For much of the 17th century, astronomers who chose to apply Kepler's elliptical theory to the determination of planetary positions used an approximation method developed by **Ismaël Boulliau**.

Kepler had a tremendous capacity for work (especially notable when one considers how much computation had to be done by hand), and several more books on astronomy followed, of which the most important were the *Epitome Astronomiae Copernicanae* (1618), a general textbook on astronomy that has not yet received much examination by historians, and the *Harmonice Mundi* (1619), buried within which is what we now call Kepler's third law, that the square of a planet's period is proportional to the cube of its mean distance from the Sun.

The long-delayed *Tabulae Rudolphinae*, published in 1627, were a kind of culmination of Kepler's astronomical work. They provided the basis for the calculation of ephemeredes of greatly increased accuracy.

Kepler expended much energy between 1615 and 1621 in the ultimately successful defense of his mother, who had been accused of witchcraft. The last decade of his life was troubled by vicissitudes attendant upon the Thirty Years' War, which broke out in 1618.

Kepler's last work, the *Somnium*, published posthumously in 1634, is an imaginative account of a visit to the Moon and a consideration of its inhabitants. Its speculations derive from his understanding of astronomy and physics, and it is now considered one of the earliest works of science fiction.

Kepler worked on and made significant contributions to fields of knowledge other than astronomy, including optics, mathematics (in the geometry of solids, close packing, tiling, and logarithms), meteorology, and, though it has long ceased to be a scientific subject, astrology. His *Dioptrice* of 1611 laid out the theory of the refracting telescope, introducing a system of two convex lenses, later known as the Keplerian telescope. What became the Kepler conjecture on close packing, which was finally proven in 1998, is more closely related to work done by **Thomas Harriot**, and – contrary to some recent accounts – Kepler and Harriot did not discuss the subject. He attempted, without success, to discover the law of refraction, whose successful formulation is now often attributed to **Willebrord Snel**, who had studied Kepler's writings on optics. Harriot, with whom he did, indeed, correspond on this topic, had earlier discovered the law but declined to reveal it to Kepler or anyone else. Among the discoveries set forth in the *Astronomiae Pars Optica*, which explores aspects of optics related to astronomical observation, is that the image projected on to the retina by the lens of the eye is inverted, leading to the realization that the process of vision is more complex than the simple receipt of the image.

Kepler was not primarily an observational astronomer, but rather a theoretician. Nonetheless, throughout his work, from his earliest model onward, his theories are conceived in very concrete or geometric models, rather than in abstract algebraic constructs. Indeed, even in his work on the mathematics of regular solids, one can easily picture Kepler physically constructing models to ease his efforts at visualization. This may partly explain why, though a prominent streak of neo-Platonism runs through his thought, notably in his faith in a Universe founded on archetypes, a case can be made that, in his philosophy, Kepler was what we now term a "realist."

Many historians and other writers have described, with varying degrees of subtlety, a Kepler who had a dual personality: a forward-looking modern rational scientist on the one hand and a mystic and obscurantist who looked backward to the Middle Ages on the other. This portrait, still sometimes presented to the public, has been superseded by the research of more recent historians, who see much of Kepler's thought as having more unity and consistency, its important theoretical innovations arising from the same milieu as the less familiar or more easily disparaged ideas, such as his improvements (as Kepler thought them) to astrology. This greater appreciation of the depth and unity of his thought does not, however, completely place Kepler's contributions within the broader history of astronomy, because even his contemporaries, and many of those who advanced the study of astronomy in the succeeding decades, were perplexed by his dynamic and harmonic theories and stymied by the complexity of the mathematical methods required to apply his astronomical discoveries in practice.

Regardless of this puzzle, it is clear that although Kepler, like Copernicus, worked within long-standing traditions, his contributions to the kinematics of astronomy were radically new, and they gave to the revolution that Copernicus had started an impetus that helped drive both astronomy and physics forward to the creation of classical dynamical physics later in the 17th century.

Adam Jared Apt

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Kerr, Frank John

Born **Saint Albans, Hertfordshire, England, 8 January 1918**
Died **Silver Spring, Maryland, USA, 15 September 2000**

Australian–American radio astronomer Frank J. Kerr was the first to map out the gas disk of the half of the Galaxy visible from the Southern Hemisphere, demonstrating the existence of spiral arms, a warp in the gas disk, and some evidence for net expansion. Joined to a northern map made in the Netherlands by Gart Westerhout, this provided the definitive picture of the Milky Way as a rotating spiral for many years.

Kerr studied physics at the University of Melbourne, receiving his B.Sc. degree in 1938 and his M.Sc. degree in 1940. He then became a staff member at the Radiophysics Laboratory in Sydney, Australia, continuing his affiliation until 1968; **Joseph Pawsey** was his key mentor during these years at the Radiophysics Laboratory. Kerr held research posts at Harvard University (where he also earned an MA in astronomy in 1951), Leiden University, and the University of Texas, and in 1962 was awarded the D.Sc. degree by Melbourne University. In 1966 he joined the faculty of the University of Maryland, where he remained for the rest of his career.

Kerr's early studies of radar and radio transmission and reception led in 1948 to his work on bouncing radar echoes off the Moon and studying the transmission and refraction of the upper ionosphere. In a classic 1952 paper he analyzed the possibility of measuring distances, structure, and motions in the Solar System using radar echoes. While visiting Harvard University, Kerr witnessed the first detection of the 21-cm line of interstellar neutral hydrogen by **Harold Ewen** and **Edward Purcell**, and upon his return to Australia embarked on what was to become his life's work, the use of this hydrogen line to study the structure of the Galaxy. He set up a Southern Hemisphere 21-cm line program, first using a 36-ft. telescope and in later years the Parkes 210-ft. radio telescope. In 1952/1953 he made the first detection and mapping observations of 21-cm hydrogen lines in galaxies other than our own, the Magellanic Clouds, showing that these relatively dust-free systems contain large amounts of cold hydrogen and demonstrating the existence of an interstellar medium of different global properties from those in the Galaxy. In 1954 Kerr, together with **Gerard de Vaucouleurs**, Brian Robinson, and James Hindman, mapped the hydrogen in the Large Magellanic Cloud, measured its extended hydrogen envelope and rotation curve, and made the first measurement of its mass.

In 1954 Kerr began his studies of our Galaxy, using the 36-ft. telescope to map hydrogen emission from the southern galactic plane. He found that hydrogen in the outer Galaxy bends away from the galactic plane in the opposite direction to that in the northern galactic plane, and invented the term "galactic warp" to describe this global distortion. Kerr hypothesized that the warp is due to tidal interaction between the galactic disk and the Magellanic Clouds. Together with Gart Westerhout and Maarten Schmidt at Leiden University, he used the northern and southern hydrogen surveys, and **Jan Oort**'s rotation model, to make the first map of the entire Galaxy. Westerhout, Kerr, and Colin Gum also used these surveys to define the location of the galactic plane and the new galactic coordinate system adopted by the International Astronomical Union [IAU] in 1958.

In 1966 Kerr moved to the University of Maryland, joining his colleague Westerhout and turning it into a major center for galactic structure studies for the next decades. Kerr's work during this period included several improvements to the hydrogen map of the Galaxy, the use of OH masers to trace the evolved stellar population throughout the Galaxy, studies of the gas dynamics in the galactic center, and investigations of the enigmatic hydrogen high-velocity clouds. He carried out much of this work at the National Radio Astronomy Observatory in West Virginia, but returned many times to Australia for extended observing periods. In the 1980s Kerr and the last of his thirteen Ph.D. students, Patricia Henning, pioneered blind searching for hydrogen emission from galaxies optically hidden by the dust in the galactic plane. Altogether, Kerr published nearly 200 scientific articles.

Kerr's service to the scientific community included the vice-presidency of the American Astronomical Society (1980–1982), directorship of the Maryland astronomy program, a term (1978–1985) as provost of the Division of Mathematical and Physical Sciences and Engineering, and some years as program director of the University Space Research Association (the organization charged with oversight of several of the national observatories) beginning in 1983. Within the International Astronomical Union, he was president of Commission (33) on structure of the Milky Way (1976–1979) and active in the commissions on interstellar matter and radio astronomy (organizing committee 1965–1968). Kerr cochaired, with Donald Lynden-Bell, the 1985 IAU committee that reevaluated the structure constants of the Milky Way, concluding that our distance from the center is closer to 8.5 than to 10 kpc, the number established 20 years earlier by Oort.

Always a loyal Australian, Kerr diligently followed Australian politics, opera, and especially sports. He was predeceased by his wife, Maureen, and one of their three children.

Woodruff T. Sullivan, III and *Gillian Knapp*

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Keśava

Flourished **Nandod, (Gujaret, India), 1496–1507**

Keśava established a line of astronomers in Nandigrāma (Nandod). He was the son of Kamālakara of the Kauśikagotra and the pupil of Vaijanātha. Keśava's three sons, Ananta, **Gaṇeśa**, and Rāma, were also noted astronomers. Gaṇeśa listed more than ten works of his father but only six survive: the *Grahakautuka*, a treatise on astronomy composed in 1496; the *Jātakapaddhati*, a popular treatise on horoscopy usually accompanied by a commentary with tables; the *Jātakapaddhativivṛti*, a commentary on the preceding; the *Tājikapaddhati*, a work on annual predictions based on Islamic astrology; the *Muhūrtatattva*, a work on catarchic astrology; and the *Sudhīrañjaṇī*.

Setsuro Ikeyama

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Keyser, Pieter [Petrus] (Theodori) Dirckszoon

Born **Emden, (Niedersachsen, Germany), *circa* 1540**
Died **Bantam (Banten, near Serang, Java, Indonesia), 13 September 1596**

Pieter Keyser, a Dutch navigator, served on one of the first trade voyages to Asia. On the basis of Keyser's and Fredrik de Houtman's observations of the southern skies, western names were given to 12 constellations of the South Celestial Hemisphere.

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Khafrī: Shams al-Dīn Muḥammad ibn Aḥmad al-Khafrī al-Kāshī

Born **probably Khafr near Shiraz, (Iran), *circa* 1470**
Died **probably (Iran), after 1525**

Khafrī was an Iranian theoretical astronomer who produced innovative planetary theories at a time well beyond the supposed period of the decline of Islamic science. Little is known about his life. Various Shīˁī writers claim Khafrī as one of their own religious scholars, and the sources assert that he was influential in the program of the Safavid Shāh Ismāˁīl (died: 1524) to make Shīˁism the official Islamic sect of Iran. The fact that Khafrī wrote works in the fields of both religion and astronomy seems to indicate that at his time and place Islamic religious scholars saw no insuperable conflict between science and religion. This appears contrary to the traditional view that science and religion were constantly at odds in Islamic society, and that, long before the lifetime of Khafrī, religious scholars effectively squelched the scientific impulse in Islam. Other examples of Islamic scientists who also were religious scholars include **Bahā' al-Dīn al-ˁĀmilī** and **Niẓām al-Dīn al-Nīsābūrī**.

Khafrī's fame as an astronomer rests mainly on his astronomical treatise *al-Takmila fī sharḥ "al-Tadhkira"* (The completion of the commentary on the *Tadhkira*). This was a commentary on **Naṣīr al-Dīn al-Ṭūsī**'s important astronomical treatise, *al-Tadhkira fī ˁilm al-hay'a* (Memoir on astronomy). As was the custom of the time, in both the Arabic and Latin worlds, a scholar often presented his own theories within the context of a commentary on the work of an esteemed author.

Consistent with the Islamic tradition in theoretical astronomy, in which astronomers had sought to reform Ptolemaic astronomy by revising **Ptolemy**'s planetary models into physically consistent forms, Khafrī presented new models. Ptolemy had devised models of planetary motion involving spheres that were required to rotate with nonuniform velocity with respect to poles (the most notorious being the equant) other than their centers. In particular, Khafrī presented new models for the motions of the Moon, the upper planets, and Mercury, some more successful than others in meeting the criticisms of earlier astronomers such as **Ibn al-Haytham**.

Khafrī's model for the lunar motion combined the best features of two previous theories, namely those of **Mu'ayyad al-Dīn al-ˁUrḍī** and **Quṭb al-Dīn al-Shīrāzī**. He managed to employ only spheres that moved uniformly around their own centers, the basic criterion for physical consistency in Islamic astronomy. Khafrī discussed various solutions to the irregular lunar motions, including those of Ṭūsī, Shīrāzī, and himself. However, there are some problems with his model. Because he attempted to make the predictions of his model coincide as closely as possible with the Ptolemaic lunar model, especially at the critical points including quadrature, his model replicated certain errors of Ptolemy's model, including the absurd prediction that the Moon should appear twice its actual size. **Ibn al-Shāṭir** had solved this problem, but Khafrī seems to have been unaware of his work. The fact that Khafrī adheres so closely to Ptolemy's observations and reproduces one of the major predictive failings of Ptolemaic theory suggests that Khafrī was more of a theorist than an observational astronomer.

Khafrī solved the equant problem for the upper planets, Mars, Jupiter, and Saturn, by following ʿUrḍī's model with a few adjustments, such as introducing a second deferent as well as an "epicyclet," *i. e.*, an epicycle on an epicycle. Again, this model essentially duplicates all of the Ptolemaic planetary positions while preserving a physically consistent model.

Khafrī described four such models for Mercury's motion, one devised by **ʿAlī Qūshjī** and three by him. Khafrī employed all of the techniques and theoretical mechanisms devised in the Islamic tradition of mathematical astronomy (the Ṭūsī Couple, epicyclets, *etc.*) and, in each case, the result was a physically consistent model.

The work of Khafrī raises the important question of the status of theoretical models in science. In the *Takmila*, Khafrī offered several possible models for the motion of Mercury, each of which was essentially equivalent in predictive power. This seems to imply that for Khafrī, the model apparently was simply a tool for predicting planetary positions. If so, then Khafrī made a significant departure from his predecessors in the entire Graeco–Islamic tradition. Alternatively, Khafrī may have been attempting to find all the possible solutions to a scientific problem, from which the scientist must employ observational criteria to choose the most correct configuration. In any case, it is not yet known what impact, if any, the work of Khafrī had or whether it led to any broad reassessment of the aims of science in Islam.

Two other works by Khafrī are mentioned in several sources, but have yet to be studied: *Muntahā al-idrāk fī al-hay'a* (The ultimate comprehension of astronomy), written as a refutation or a commentary on the *Nihāyat al-idrāk fī dirāyat al-aflāk* (The ultimate understanding of the knowledge of the orbs) of Shīrāzī; and *Ḥall mā lā yanḥall* (Resolution of that not [yet] solved).

Glen M. Cooper

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Saliba, George (1994). *A History of Arabic Astronomy: Planetary Theories during the Golden Age of Islam*. New York: New York University Press. (This is a collection of articles that are useful in that they probe deeply into several discrete figures and issues from the history of Islamic astronomy. Saliba provides helpful clarifications of a number of historical issues, including the nature of the apparent connection between the work of Islamic astronomers of the "Marāgha School" and the achievement of Nicolaus Copernicus.)

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Khaikin, Semyon Emmanuilovich

Born **Minsk, (Belarus), 21 August 1901**
Died **Leningrad (Saint Petersburg, Russia), 30 July 1968**

Semyon Khaikin was a Soviet physicist and radio astronomer, a pioneer and visionary in observational radio astronomy who predetermined the strategy of its development in the USSR for decades to come. During the 1947 solar eclipse in Brazil, Khaikin became the first to observe the radio (1-m) emission of the Sun's corona.

A graduate (1928) of Moscow University, Khaikin also taught there from 1930 to 1946. In 1931–1933 he was deputy director of the Physical Institute within the Moscow University, in 1934–1937 the dean of the Physical Faculty, and in 1937–1946 the chair of the Department of General Physics. Concurrently, in 1945–1953, he conducted research at the Lebedev Physical Institute of the Soviet Academy of Science [PhIAN]. After World War II, Khaikin headed the creation of the first Soviet radio astronomical station in Crimea.

During Stalin's anti-Semitic (so called anticosmopolitan) campaign, Khaikin was forced to leave Moscow University and soon moved to Pulkovo Observatory near Leningrad, where he founded and ran the Department of Radio Astronomy (1953). He was the principal designer of a special type of new radio telescope with an antenna of changing profile for a higher angular resolution; RATAN-600, the largest telescope in the world of such a type, was erected later on the Northern Caucuses side by side with the great 6-m optical telescope [BTA].

Alexander A. Gurshtein

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Khalīfazāde Ismāʿīl: Khalīfazāde Çınarī Ismāʿīl Efendi ibn Muṣṭafā

Died **(Turkey), probably 1790**

Khalīfazāde Ismāʿīl was an Ottoman astronomer, astrologer, timekeeper (*muwaqqit*), and astronomical instrument maker. He lived and worked in Istanbul, but we have no information about the date and place of his birth. The title *Çınarī* in some of his manuscripts implies that he lived in the Çınar district, also known as Sancaktar Hayrettin. The name Khalīfazāde derived from the profession of his father Muṣṭafā Efendi, who was a *khalīfa* (experienced apprentice) of *mukābele-i piyāde* and worked in the barracks at Sumnu (in Bulgaria). *Mukābele-i piyāde* was an office under the Treasury that enlisted infantry and handled the paper work for their salaries. This was also Khalīfazāde Ismāʿīl's first position, and it required mathematical skills; he worked in the same office as a *şākird* (apprentice) in 1755, and then was promoted *başhalife*.

Probably the earliest work of Khalīfazāde is a sundial that he most likely completed as an apprentice. This vertical sundial still exists and is located at the southwest wall of the Hekimoğlu Ali Pasha Mosque in the neighborhood of Çınar where Khalīfazāde lived. The inscription on the sundial notes that it was engraved in 1761 by Khalīfazāde Ismāʿīl.

In 1767, Khalīfazāde was appointed as *muwaqqit* to the Laleli Mosque (also called the Sultan Muṣṭafa III Mosque) and remained there until 1789. During this period he compiled or translated a number of works on astronomy, astrology, and mathematics. In 1767, Khalīfazāde constructed a horizontal sundial engraved on marble that is no longer extant, but which partially existed until the end of the 19th century. However, located at the base of the west minaret of the Laleli Mosque are two other vertical sundials made by him. The larger of the two was completed in 1779. Although the lines of the sundials are not sharp, the inscription is still legible and states that it was "engraved by muwaqqit Ismāʿīl."

The Ottoman Sultan Muṣṭafā III (reigned: 1757–1774), who was particularly fond of astrology, asked Khalīfazāde to translate two studies on astronomy from French to Turkish; this indicates that he had some knowledge of French, but we have no information on how he acquired this knowledge. The first translation, *Rasad-i qamar* or *Terceme-i Zīc-i Clairaut*, was related to the movements of the Moon and was probably based on **Alexis Clairaut**'s (1713–1765) astronomical work entitled *Théorie de la lune*. Two copies exist: The first is Istanbul, Kandilli Observatory Library MS 244 (which is the author's copy), completed in 1767 and dedicated to Muṣṭafā III; a second copy is Kandilli Observatory Library MS 190, completed in 1767.

Khalīfazāde's second translation, also at the request of Muṣṭafā III, was of **Jacques Cassini**'s (1677–1756) *Tables astronomiques du soleil, de la lune, des planètes, des étoiles fixes et des satellites de Jupiter et de Saturne* (Paris, 1740). Completed in 1772, it was named *Tuhfe-i Behīc-i Rasīnī Terceme-i Zīc-i Cassinī.* (Copies include Istanbul, Topkapı Palace Museum Library, Hazine MS 451, copied by F. Karatay in 1772 and dedicated to Muṣṭafā III; and Kandilli Observatory Library MS 228.) This work, known as Cassini's *Zīj*, was significant for two main reasons. First, it introduced logarithms to the Ottomans; furthermore, Khalīfazāde added tables to the translation giving the logarithms for sines and tangents of arcs from 0° to 45° to the level of minutes, and he also provided logarithmic tables for integers from 1 to 10,000. Second, this *zīj* influenced Ottoman timekeeping. **Ulugh Beg**'s *zīj* was abandoned during Sultan Selim III's reign (1789–1807) due to its errors (as much as 1 hour) and replaced with calendars and astronomical calculations based on Cassini's *zīj* beginning in 1800. This *zīj* was then used for almost 30 years.

Khalīfazāde Ismāʿīl Efendi wrote other works in the fields of astronomy, astrology, and mathematics that can be found listed in *Osmanli Astronomi Literatürü Tarihi* and *Osmanli Matematik Literatürü Tarihi.*

Meltem Akbas

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Khalīlī: Shams al-Dīn Abū ʿAbdallāh Muḥammad ibn Muḥammad al-Khalīlī

Flourished **Damascus, (Syria), *circa* 1365**

Khalīlī was an astronomer associated with the Umayyad Mosque in the center of Damascus. A colleague of the astronomer **Ibn al-Shāṭir**, he was also a *muwaqqit* – *i. e.*, an astronomer concerned with ʿ*ilm al-mīqāt*, the science of timekeeping by the Sun and stars and regulating the astronomically defined times of Muslim prayer. Khalīlī's major work, which represents the culmination of the medieval Islamic achievement in the mathematical solution of the problems of spherical astronomy, was a set of tables for astronomical timekeeping. Some of these tables were used in Damascus until the 19th century, and they were also used in Cairo and Istanbul for several centuries. The main sets of tables survive in numerous manuscripts, but they were not investigated until the 1970s.

Khalīlī's tables can be categorized as follows:

(1) tables for reckoning time by the Sun, for the latitude of Damascus;
(2) tables for regulating the times of Muslim prayer, for the latitude of Damascus;
(3) tables of auxiliary mathematical functions for timekeeping by the Sun for all latitudes;
(4) tables of auxiliary functions for finding the solar azimuth from the solar altitude for any latitude;
(5) tables of auxiliary functions for solving the problems of spherical astronomy for all latitudes;
(6) a table displaying the *qibla*, *i. e.*, the direction of Mecca, as a function of terrestrial latitude and longitude for each degree of both arguments; and
(7) tables for converting lunar ecliptic coordinates to equatorial coordinates.

(Paris, Bibliothèque Nationale MS ar. 2558, copied in 1408, contains all of the tables in Khalīlī's major set [1, 2, 5 and 6]. Dublin, Chester Beatty MS 4091 and Bursa, Haraççioğlu MS 1177,4 are unique copies of the minor auxiliary tables [3] and [4], respectively.)

The first two sets of tables correspond to those in the large corpus of spherical astronomical tables computed for Cairo that are generally attributed to the 10th-century Egyptian astronomer **Ibn Yūnus**.

Khalīlī's fifth set of tables was designed to solve all the standard problems of spherical astronomy, and they are particularly useful for those problems that, in modern terms, involve the use of the cosine rule for spherical triangles. Khalīlī tabulated three functions and gave detailed instructions for their application. The functions are the following:

$$f_\phi = \sin\theta/\cos\phi \text{ and } g_\phi = \sin\theta\tan\phi$$
$$K(x,y) = \text{arc}\cos\{x/\cos y\},$$

computed for appropriate domains. The entries in these tables, which number over 13,000, were computed to two sexagesimal digits and are invariably accurate. An example of the use of these functions is the rule outlined by Khalīlī for finding the hour angle *t* for given solar or stellar altitude *h*, declination δ, and terrestrial latitude *φ*. This may be represented as:

$$t(h,\delta,\phi) = K\{[f_\phi(h) - g_\phi(\delta)],\delta\}$$

and it is not difficult to show the equivalence of Khalīlī's rule to the modern formula

$$t = \text{arc}\cos\frac{\{\sin h - \sin\delta\sin\phi\}}{\cos\delta\cos\phi}.$$

These auxiliary tables were used for several centuries in Damascus, Cairo, and Istanbul, the three main centers of astronomical timekeeping in the Muslim world. They were first described in 1973. In 1991 Glen Van Brummelen, in his statistical investigation of the errors in the entries, determined that the tables of (7) had been computed first and the tables of (6) were computed from these. In 2000, the fourth set of Khalīlī's tables was discovered in a manuscript in Bursa. These were compiled before the fifth set and also contain a set of tables of (7); when compiling his main set (5), Khalīlī simply took over the tables of (7) from this earlier set (4). So Van Brummelen's hypothesis was confirmed.

Khalīlī's computational ability is best revealed by his *qibla* table. The determination of the *qibla* for a given locality is one of the most complicated problems of medieval Islamic trigonometry. If (L,φ) and (LM,φ_M) represent the longitude and latitude of a given locality and of Mecca, respectively, and $\Delta L = |L - LM|$, then the modern formula for $q(L,\varphi)$, the direction of Mecca for the locality, measured from the south, is

$$q = \text{arc}\cot\frac{\{\sin\phi\ \cos\Delta L - \cos\phi\ \tan\phi_M\}}{\sin\Delta L}.$$

Khalīlī computed $q(L,\varphi)$ to two sexagesimal digits for the domains $\varphi = 10°, 11°, \ldots, 56°$ and $\Delta L = 1°, 2°, \ldots, 60°$; the vast majority of the 2,880 entries are either accurately computed or in error by $\pm 1'$ or $\pm 2'$. Several other *qibla* tables based on approximate formulas are known from the medieval period. Khalīlī's splendid *qibla* table does not appear to have been widely used by later Muslim astronomers.

David A. King

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Khaljī: Maḥmūd Shāh Khaljī

➜ **Cholgi: Maḥmūd Shāh Cholgi**

Kharaqī: Shams al-Dīn Abū Bakr Muḥammad ibn Aḥmad al-Kharaqī [al-Khiraqī]

Flourished	**Marw (Merv near Mary, Turkmenistan)**
Died	**1138/1139**

Kharaqī is the author of two works on *hay'a*, a genre of the Arabic astronomical literature that placed its main emphasis on explaining the physical structure of the Universe. The shorter of these, *al-Tabṣira fī ˁilm al-hay'a* (Conspectus of the science of astronomy), achieved considerable popularity. Altogether, about a dozen manuscripts survive (including several copied into Hebrew letters). Two commentaries were written, one by the Yemeni Jew Alu'el ben Yeshaˁ, the other anonymous; and a Hebrew translation has been identified. Only a few manuscript copies of the longer work, *Muntahā al-idrāk fī taqāsīm al-aflāk* (The utmost attainment in the configuration of the orbs) survive. Neither work has been published or even been the subject of a close study.

Kharaqī's work constitutes an important stage in the physical investigations of Islamic astronomers. He acknowledges the work of predecessors such as **Ibn al-Haytham** who had put their minds to this task. Yet, Kharaqī proclaims, people still do not know how the stars carry out their motions. It is like knowing that a person went from one city to another, but not knowing whether he went by foot or on horseback. His own work aims to rectify the matter. Although no specific advances can yet be credited to al-Kharaqī, his writings were an influence upon **Naṣīr al-Dīn al-Ṭūsī**.

Y. Tzvi Langermann

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Khayyām: Ghiyāth al-Dīn Abū al-Fatḥ ˁUmar ibn Ibrāhīm al-Khayyāmī al-Nīshāpūrī

Born	**Nīshāpūr, Khurāsān, (Iran), 18 May 1048**
Died	**Nīshāpūr Khurāsān, (Iran), *circa* 1123**

Better known in the West as ˁUmar Khayyām, Khayyām was one of the most prominent scholars of medieval times, with remarkable contributions in the fields of mathematics and astronomy. His worldwide fame today mainly comes from a number of quatrains attributed to him that have tended to overshadow his brilliant scientific achievements. Besides his ingenious achievements in mathematics, Khayyām is said to have supervised or actively taken part in the formulation and compilation of a solar calendar that potentially surpasses all calendar systems ever composed in precision and exactness – a legacy alive today in his native Iran. Khayyām's contributions to astronomy should be viewed within the context of his efforts to compile this calendar.

Nīshābūr was known for its great learning centers and its prominent scholars. Khayyām studied the sciences of the day in his native town and is said to have mastered all branches of knowledge in early youth. Khayyām soon rose to prominence in Khurāsān, the political center of the powerful Saljūq dynasty that ruled over a vast empire extending from the borders of China to the Mediterranean. As the leading scientist, philosopher, and astronomer of his day, he enjoyed the support and patronage of the Saljūq court.

With the ascent of Jalāl al-Dīn Malik Shāh to the throne, in 1072, Isfahān was chosen as the new capital of the Saljūq dynasty. Consequently, a group of prominent scientists and scholars from Khurāsān, among them Khayyām and **al-Muẓaffar al-Isfizārī**, were summoned to the court in the new capital to embark on two grand projects: the construction of an observatory and the compilation of a new calendar to replace the existing calendars. In addition to other deficiencies, these calendars had proved inefficient in monetary and administrative matters related to time-reckoning. No details have survived regarding the observatory and its site, except for brief notes saying that huge sums of money were spent on it and that it was very well equipped. However, one finds references made by **Naṣīr al-Dīn al-Ṭūsī**, **Quṭb al-Dīn al-Shīrāzī**, and others to a *Zīj-i Khayyām* or *Zīj-i Malikshāhī* (Astronomical handbooks of Khayyām or Malikshāh) that could possibly be one major outcome of the observatory.

By 1079, a solar calendar was developed that was named the "Jalālī" or "Malikī" calendar, thus carrying the name of the monarch who was the project's patron. The most remarkable feature of the new calendar was the correspondence of the beginning of the year (*Nowrūz* or new day) and the beginning of Aries, *i. e.*, where the Sun passing from the Southern Celestial Hemisphere to the northern appears to cross the Celestial Equator, marking the beginning of spring or the vernal equinox. The Jalālī year was a true solar year that followed the astronomical seasons. The length of this year was the mean interval between two vernal equinoxes. Recent studies have underscored the advantage of the Jalālī calendar by demonstrating the superiority of the vernal equinox as a calendar regulator, arguing that the vernal equinox year length is much more consistent than other natural regulating points.

The second important feature of this calendar was the introduction for the first time of leap years using the rule of quinquennia (5-year periods for leap years). After a normal period of 7 quadrennia (4-year periods for leap years – in exceptional cases 6 or 8), there comes a quinquennia in which the extra day is added to the 5th and not the 4th year as usual. This produces patterns of 33-, 29- and 37-year cycles for 7, 6, and 8 quadrennia, respectively. As modern calculations have shown, this introduction of 5-year leap-days into the calendar has the potential, provided that a correct pattern is employed, of rendering the calendar quite accurate over relatively long time spans – indeed, more accurate than the modern Gregorian calendar. There is, however, a wide variety of opinions on the pattern (the number of times 29 or 37 cycles are combined with 33-year cycles) of leap years originally built into the Jalālī calendar, thus leaving its actual accuracy an open question to be investigated.

Khayyām's major role in the court of Malik-Shāh, as well as the historical testimony of prominent astronomers such as Ṭūsī, Shīrāzī, and **Nīsābūrī**, all associating the name of ʿUmar Khayyām with the Jalālī calendar, leaves little doubt of his leading role in the compilation of the Jalālī calendar. His prominence as a major astronomer of his time is also borne out by his critical notes on **Ibn al-Haytham**'s *Maqāla fī ḥarakat al-iltifāf* (Treatise on the winding motion). This work, which is discussed by Shīrāzī, demonstrates the fact that Khayyām had been engaged in quite complicated and difficult aspects of theoretical astronomy that involved the development of new models to replace the unwieldy latitude models of **Ptolemy**.

Khayyām's work in astronomy has been overshadowed by his outstanding achievements in mathematics, in which his genius and originality are best manifested. His contributions to the subject may well be considered some of the greatest during the entire Middle Ages. In particular, his treatise entitled *Risāla fī al-barāhīn ʿalā masāʾil al-jabr wa-ʾl-muqābala* (Treatise on the proofs of the problems of *al-jabr* and *al-muqābala*) is one of the most important algebraic treatises of the Middle Ages. He also dealt with the socalled parallel postulate and arrived at new propositions that were important steps in the development of non-Euclidean geometries. His work in the theory of numbers was also significant, eventually leading to the modern notion of real positive numbers that included irrational numbers.

Khayyām also wrote short treatises in other fields such as mechanics, hydrostatics, the theory of music, and meteorology. Through his work in ornamental geometry, he contributed to the construction of the north dome of the Great Mosque of Isfahān. He may have also served as a court physician.

Though little remains of his work in philosophy, Khayyām was a follower of **Ibn Sīnā** and much respected by his contemporaries for his work in this field. In a later work, he concludes that ultimate truth can be grasped only through mystical intuition. This perhaps gives some inkling of how to read his famous poetry, not all of which has been accepted as authentic by modern scholarship.

Khayyām seems to have spent the most fruitful scientific years of his life in Isfahān. But with the assassination of Malikshāh in 1092, he returned to Khurāsān, spending the rest of his life in Marw and Nīshāpūr. His death brought to an end a brilliant chapter in Iranian intellectual history.

Behnaz Hashemipour

Alternate name

Omar Khayyām

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Khāzin: Abū Jaʿfar Muḥammad ibn al-Ḥusayn al-Khāzin al-Khurāsānī

Born **probably Khurāsān, (Iran)**
Died ***circa* 971**

Abū Jaʿfar al-Khāzin was an astronomer and mathematician whose main work was the *Zīj al-ṣafāʾiḥ* (*zīj* of the plates). A *zīj* is an astronomical handbook; "plates" here refer to the plates of an astronomical instrument, like an astrolabe or an equatorium. This work was considered by later scholars as the best work in this field.

Abū Jaʿfar al-Khāzin was a Sabian of Persian origin. (The Sabians were a Hellenized, pagan sect that was tolerated in early Islam.) He was called al-Khurāsānī, meaning from Khurāsān, a province in eastern Iran. Khāzin was attached to the court of the Būyid ruler Rukn al-Dawla (932–976), Prince of Rayy (a town near Tehran destroyed in the 12th century). There he benefited from the patronage of Abū al-Faḍl ibn al-ʿAmīd, the vizier of Rukn al-Dawla, and his fame reached Baghdad. In 953/954 Khāzin played the role of negotiator in the war in which the army of Nūḥ ibn Naṣr of Khurāsān opposed Rukn al-Dawla.

As an astronomer, Khāzin knew and commented upon the works of earlier astronomers. For instance, he wrote a commentary on **Ptolemy**'s *Almagest* in which he provided information regarding the astronomical activities of early Islamic astronomers.

Later authors mention the astronomical observations carried out by Khāzin. He measured the obliquity of the ecliptic at Rayy in 960. This measurement was ordered by the aforementioned Vizier Ibn al-ˁAmīd, who also ordered the construction of a mural quadrant in Rayy. Khāzin, together with another astronomer called al-Khirāwī, measured the obliquity of the ecliptic with this instrument. We are also told of the determination of the latitude made by Khāzin and a number of collaborators using a ring of 4 m. Another source mentions observations made in Kāshān on 6 October 960, also ordered by Ibn al-ˁAmīd, in order to obtain the latitude of this city. In 970 he also measured the obliquity of the ecliptic in Edessa.

Khāzin was not only a good observer but also a theoretician. He believed in the solid character of the heavenly spheres, supported the theory of the progressive diminution of the obliquity of the ecliptic, and, probably, the theory of the trepidation of the equinoxes along an arc of 8° on the ecliptic.

Among his writings there is a *maqāla* in which Khāzin developed a solar model without eccentrics and epicycles. This *maqāla* is not preserved, but there are some references to it preserved in some of the works of **Bīrūnī**. It was a homocentric model in which the Sun has a circular motion with the Earth as the circle's center, but in such a way that its motion is uniform with respect to a point that does not coincide with the center of the Universe. In this model the Sun moves on a circle, which is concentric and coplanar with the ecliptic, at a variable speed. The uniform movement of the Sun takes place on a different circle. The distance between the centers of these two circles has the same value as the Ptolemaic eccentricity. But there is neither an apogee nor a perigee, contrary to the Ptolemaic model, although the line joining the two centers intersects the circle of the Sun's path where it reaches its minimum and maximum speeds. This system reappeared in a more complete version in the 14th century, in the work of the astronomer **Henry of Langenstein** entitled *De reprobatione ecentricorum et epiciclorum* (1364).

Khāzin was also the author of a book (now lost) entitled *Kitāb al-abˁād wa-'l-ajrām*, in which he gave the diameters of stars from the first to the sixth magnitude but without saying how he obtained these values.

The *Zīj al-Ṣafā'iḥ*, written for Ibn al-ˁAmīd, dealt with a variant of the astrolabe. This work was considered lost for a long time, but in the late 1990s a manuscript with a copy of an incomplete text of this treatise was found in the Research Library of the Government of Srinagar in India (number 314). Pages 17–87 and pages 95–102, as well as in all likelihood some of the last part of the manuscript (215b–?), are missing in the copy. The lost pages contain the details of the construction of the instrument and the use of the planetary plate of the instrument. In the first page of the treatise there is an index of the contents from which we can confirm that the treatise is divided into two books (or *maqālāt*) as reported by later authors. The first book of the treatise deals with the computation of the longitude and latitude of the planets. This analysis is preceded by an introduction that is mostly theoretical. The second book is divided into seven chapters. It deals with the astronomy of the *primum mobile*, calculations of spherical astronomy, and the elements of trigonometry that are necessary to carry them out. The instrument described contains a whole set of orthogonal lines that provide graphical solutions for the standard astronomical problems usually solved by a *zīj* or by an astrolabe; Khāzin, however, uses a *safīḥat al-juyūb*, a plate of sines, instead of a conventional astrolabe with its plates.

One such instrument was made by Hibat Allāh ibn al-Ḥusayn al-Asṭurlābī, an astrolabist of early 12th-century Baghdad. He constructed the instrument in the year 513 of the Hijra (1120). The instrument was still extant at the beginning of the 20th century in Germany, but it subsequently disappeared. Photographs of this instrument were published and analyzed by David King. In the late 1990s the instrument was rediscovered in Berlin. It has more plates than the ones depicted in the preserved photographs and awaits a deeper study.

In mathematics Khāzin was the first to show that a cubic equation of the form $x^3 + c = ax^2$ could be solved geometrically by means of conic sections. He stated that the equation $x^3 + y^3 = z^3$ did not have a solution in positive integers, but he was unable to give a correct proof. Khāzin also worked on the isoperimetric problem and wrote a commentary to Book X of Euclid's *Elements*.

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Khāzinī: Abū al-Fatḥ ˁAbd al-Raḥmān al-Khāzinī (Abū Manṣūr ˁAbd al-Raḥmān, ˁAbd al-Raḥmān Manṣūr)

Flourished **Marw, (Merv near Mary, Turkmenistan), first half of the 12th century**

Khāzinī was known for scientific activity in the fields of astronomy, mechanics, and scientific instruments. A slave of Greek origin in his youth, he later converted to Islam and received a distinguished scientific education. He had a reputation for asceticism, devotion, and piety. Khāzinī worked in the court of the Saljūq ruler Sanjar ibn Malik-Shāh (reigned: 1118–1157), and dedicated two of his most important writings to him: *al-Zīj al-Sanjarī*, an astronomical handbook with tables for Sanjar, and his encyclopedic *Kitāb mīzān al-ḥikma*, a major work on mechanical knowledge, specific gravity, and the like. His other known works include a treatise on astronomical instruments (*Risāla fī al-ālāt*) and a text on a self-rotating sphere (*Maqāla fī ittikhādh kura tadūru bi-dhātihā*).

Khāzinī's main astronomical work is the *Zīj al-muʿtabar al-sanjarī al-sulṭānī*, a lengthy astronomical handbook with tables, dedicated to Sultan Sanjar and compiled after 1118, in the aftermath of the work done reforming the solar calendar (the "Jalālī calendar"). It is preserved in two incomplete manuscript copies (British Library MS Or 6669 and Vatican Library MS Ar 761), and in a revised abridgment called *Wajīz al-zīj al-muʿtabar al- sulṭānī*, made by Khāzinī himself in 1130/1131. This version was translated into Greek in the late 1290s by **Gregory Chioniades**, an Orthodox bishop, upon his return to Constantinople from Tabrīz and then utilized by Byzantine scholars such as George Chrysococces (in Trebizond, *circa* 1335–1346) and **Theodore Meliteniotes** (in Constantinople, *circa* 1360–1388). It became a basis for the revival of astronomy then taking place in the Byzantine Empire. Since the two extant manuscripts of Khāzinī's *Zīj* lack several parts, the existence of the *Wajīz* is very helpful for the recovery of some of the missing material, although the canons and the tables contained within it have both been drastically revised; for example, the original *Zīj* contains 145 tables, whereas the *Wajīz* has only 45.

Among other things, *al-Zīj al-sanjarī* includes numerous tables related to chronology and calendars as well as various tables for calculating holidays and fasting, material related to the theory of Indian cycles, important developments in the theory of planetary visibility, and an elaborate set of eclipse tables. The section on visibility tabulates the arcs of visibility for the five planets as well as those for the Moon, and it also presents differences according to climes.

Khāzinī undoubtedly made a certain number of astronomical observations, though they seem to be limited in number. **Quṭb al-Dīn al-Shirāzī** implied that Khāzinī must have had technical competence and access to good instruments since his determination of the obliquity was carefully made. In the introduction to his *Zīj*, Khāzinī describes several astronomical instruments and observational techniques, and he asserts in the canons that he bases his astronomy on observations and sound theory. Further, he states at the beginning of the *Wajīz* that he compared, observed, and calculated positions for all the planets as well as for the Sun and Moon, at conjunctions and eclipses.

Khāzinī was familiar with the astronomy of his predecessors, especially **Bīrūnī**, **Thābit ibn Qurra**, and **Battānī**. His *Zīj* seems to be influenced by their work in addition to his own observations. Throughout his *Zīj*, he reports the methods and conclusions of Thābit and Battānī. For instance, for predicting the crescent visibility, Khāzinī proposes a sophisticated mathematical method that can be traced back to Thābit's *Fī Ḥisāb ru'yat al-ahilla*.

Another astronomical work by Khāzinī is his treatise on astronomical instruments. The text, a short work in 17 folios, is composed of seven parts, each devoted to a different instrument: a triquetrum, or parallactic ruler, a diopter for measuring apparent diameters, an instrument in the shape of a triangle, a quadrant (but called a *suds* or sextant), an instrument involving reflection, an astrolabe, and devices for aiding the naked eye. All the instruments in this text are treated in a general way, and there is no reference to any special observatory.

Khāzinī's text on *The Self-Rotating Sphere* demonstrates his interest in connecting astronomy and applied mechanics. This text, probably the earliest of his extant works, describes a celestial globe that works with weights. An instrument, in the shape of a solid sphere and marked with the stars and the standard celestial circles, is suspended halfway within a box. The sphere is mounted so as to rotate once a day propelled by a weight falling from a leaking reservoir of sand. This automated celestial instrument may be used to find arcs of importance in spherical astronomy.

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Khujandī: Abū Maḥmūd Ḥāmid ibn al-Khiḍr al-Khujandī

Born **Khujand, (Tajikstan), *circa* 945**
Died **1000**

Khujandī was an astronomer of some repute who constructed a variety of instruments and contributed to the mathematics supporting astronomical work. He is best known for the first very large mural quadrant that was intended to make solar observations of unprecedented accuracy. Only a few details are known of his life; he was likely one of the khans of Khujanda in Transoxania and was supported by the Būyid ruler Fakhr al-Dawla.

Khujandī's towering achievement, the giant mural sextant near Rayy, was perhaps the most ambitious instrument of its time. Named *al-suds al-Fakhrī* (after its sponsor Fakhr al-Dawla), it consisted of 60° of a meridian arc about 43 m in diameter, built at and below ground level. A small aperture in the roof of the building that housed the instrument allowed a cone of the Sun's rays to shine through. A circle with crosshatch lines was placed on the rays that fell onto the scale in order to determine their center. The scale was marked to 10″, making it the first instrument capable of measuring with a precision better than minutes.

In 994 Khujandī used the *suds al-Fakhrī* to measure meridian transits near solstices; from this he obtained the value $\varepsilon = 23;32,19°$ for the obliquity of the ecliptic, and a value of 35;34,38.45° for the latitude of Rayy (accurate to within one′). On the basis of earlier determinations of ε, Khujandī decided that ε is a variable quantity, a conclusion with which **Bīrūnī** disagreed. In his *Taḥdīd al-amākin,* Bīrūnī discusses Khujandī's work in detail. He argues that the measurements failed to produce the expected accuracy because the building settled between the summer and winter solstices, causing the height of the aperture in the roof to drop. After the failure of the *suds al-Fakhrī*, the observational program probably continued with armillary spheres and other instruments, and Khujandī eventually produced the *Zīj al-Fakhrī* (an astronomical handbook) on the basis of his results. (A partially extant Persian *zīj* written 200 years later may also derive from Khujandī's observations.) Although the large instrument was an immediate failure, it was a model for similar instruments at the observatories in Marāgha and Samarqand in the 13th and 15th centuries, respectively. These avoided the problem of settling by using different construction materials.

Astronomical instruments are a recurring interest in Khujandī's other works. A treatise entitled *The Comprehensive Instrument* describes an invention called a *shāmila* designed to replace the astrolabe or a quadrant. It was not universal in the sense that it was restricted for use in a particular range of terrestrial latitudes.

Two geometric methods of drawing azimuth circles on an astrolabe are credited to Khujandī by other medieval authors. He constructed an astrolabe in 984/985, which is one of the earliest still extant. It is considered to be one of the most important surviving astronomical instruments.

Khujandī composed several mathematical works, among them a text on geometry and a flawed proof of Fermat's last theorem for $n = 3$. He is also one of several competing claimants to the rule of four quantities, a theorem in spherical trigonometry that was simpler than Menelaus' theorem and, for many Muslim astronomers, replaced it as the basic tool of spherical astronomy.

Glen Van Brummelen

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Khwārizmī: Muḥammad ibn Mūsā al-Khwārizmī

Born ***circa* 780**
Died ***circa* 850**

Khwārizmī was a well-known astronomer and mathematician who spent most, if not all, of his scholarly life in Baghdad, in close connection with the ˤAbbāsid court, particularly during the caliphate of **Ma'mūn** (reigned: 813–833). There is some confusion about his origins. The 10th-century bibliographer Ibn al-Nadīm claimed that Muḥammad ibn Mūsā was from Khwārizm in Central Asia, whereas the historian Ṭabarī reported that Khwārizmī was also known as al-Quṭrabbulī, a name associating the scholar with a town not far from Baghdad rather than with the Central Asian region of Khwārizm (Toomer, p. 358). Ṭabarī added that he was also called al-Majūsī, a designation that indicates that Khwārizmī was a Zoroastrian rather than a Muslim. Ibn al-Nadīm also stated that he was attached to the *Bayt al-ḥikma*, the caliphal library. What this means exactly is unclear since there is considerable modern controversy about this institution and whether it should be regarded simply as a library or as a translation bureau and scientific research institution.

Ibn al-Nadīm lists four astronomical works: the *Zīj al-Sindhind* (an astronomical handbook according to the *Sindhind*), a treatise on the sundial, and two works on the astrolabe. Of these, the first is no longer extant in Arabic but is available in Latin translation; the second seems to be extant as are fragments of a work on the astrolabe. Rosenfeld and Ihsanoğlu list 20 astronomical works in all. Among Khwārizmī's nonastronomical works at least two are mathematical: a book on Indian arithmetic and one devoted to algebra. (A book on "addition and subtraction" is also attributed to him.) He also has a *Book on Geography*, which is extant, and a *Book on History*, which is not but was quoted by later authors. The *Algebra* and the *Zīj* were dedicated to Caliph Ma'mūn. The treatise on Indian arithmetic in its extant Latin translation mentions the *Algebra* and hence was produced later. Khwārizmī also wrote a description of the Jewish calendar, which was written not before 823/824 because one of its examples is carried out for that year. The other texts offer no clue for dating them.

Khwārizmī's *Zīj al-Sindhind* confirmed the place of pre-Islamic Indian astronomical models, functions, and parameters in the scholarly community of Baghdad, which had been multicultural since the second half of the 8th century. Before him, several "Zījāt al-Sindhind" are said to have been compiled based on Arabic translations of Indian astronomical handbooks (Pingree 1970, p. 105). Indeed, the astronomer **Ibn al-Ādamī** described Khwārizmī's *Zīj* as an abridgment, prepared for Ma'mūn, of **Fazārī**'s (second half of the 8th century) handbook *al-Sindhind* (Pingree 1970, p. 106). Khwārizmī's tables were known to astronomers not only in Baghdad, but also in Central Asia in the east and in Andalusia on the Iberian Peninsula in the west. A number of authors who compiled their own handbooks relied on it. Two examples are the already-mentioned Ibn al-Ādamī in Baghdad, in his nonextant astronomical handbook *Naẓm al-ʿiqd*, and **Ibn Muʿādh** in Andalusia, whose handbook is extant in its Latin translation *Tabulae Jahen*. Others commented on Khwārizmī's tables, often criticizing the methods used, such as **Aḥmad ibn Kathīr al-Farghānī** (9th century) in Baghdad, **Ibn al-Muthannā** (10th century?) in Andalusia, ʿAbdallāh ibn Masrūr al-Ḥāsib al-Naṣrānī in Baghdad (9/10th centuries), and **Abū Rayḥān al-Bīrūnī** in Ghazna. Bīrūnī devoted three treatises to Khwārizmī's *Zīj*. In one of them he defended Khwārizmī against attacks of Aḥmad ibn al-Ḥusayn al-Ahwāzī (10th century) (Muḥammad ibn Mūsā 1983, p. 21). It is believed that as late as the 19th century, tables connected to Khwārizmī's *Zīj* were copied in Egypt (Goldstein and Pingree 1978; Pingree 1983).

No copy of Khwārizmī's *Zīj* has survived, but Hebrew and Latin versions of various later texts connected with Khwārizmī's tables are extant. Ibn al-Muthannā in Andalusia set out to compose a commentary in order to rectify the obscurities of a critique of Khwārizmī's tables written by Farghānī. Both commentaries are lost. But Hebrew and Latin versions of Ibn al-Muthannā's commentary are extant (Goldstein 1967, pp. 5–6; Pedersen, p. 32). The Latin translation of Ibn al-Muthanna's commentary was made by Hugo of Santalla (12th century) (Millás Vendrell, 1963). One Hebrew translation was produced by **Abraham ibn Ezra** (Goldstein 1967, p. 3). In the same century as Ibn al-Muthannā and also in Andalusia, **Maslama ibn Aḥmad al-Majrīṭī** edited Khwārizmī's tables. Majrīṭī's student **Ibn al-Ṣaffār** is believed to have continued the editorial work of his teacher (Toomer, p. 358). This edition was translated in the 12th century into Latin presumably by **Adelard of Bath**. Other Latin manuscripts contain texts that seem to combine extracts from Ibn al-Muthanna's commentary, Majrīṭī's edition, and one or more Arabic compilations of material, translated and revised into Latin, from the tables of Khwārizmī, **Yaḥyā ibn Abī Manṣūr**, **Muḥammad ibn Jābir al-Battānī**, Ibn al-Muthannā, and Majrīṭī (Pedersen, pp. 31–46). The *Toledan Tables*, compiled around 1060 in Muslim Spain, contain several tables from Khwārizmī's *Zīj*, some of which are not found in Majrīṭī's revision. They are lost in Arabic, but extant in several Latin versions (Van Dalen, p. 200).

The extant texts and tables follow in their presentation of the material; in their methods, rules, and models; and in several of their parameter values astronomical knowledge and practice as taught in several treatises written by Hindu scholars between the 5th and 7th centuries. They also use elements from Sasanian astronomical tables, incorporate borrowings from Greek astronomical writings (in particular **Ptolemy**'s *Almagest* and *Handy Tables*), and include values determined by observations carried out during Ma'mūn's reign. A survey of the character of the tables in the Latin translation of Majrīṭī's revision of Khwārizmī's *Zīj* has recently been given by Van Dalen (pp. 200–211). Khwārizmī's original *Zīj* has been described as a similar mixture of elements by Ibn al-Ādamī, who, according to Ibn al-Qifṭī (1173–1248), had reported that Khwārizmī had relied in his work on the mean motions of the Indian tradition, but differed from it in the equations and the declination. Ibn al-Ādamī also asserted that Khwārizmī followed Sasanian sources with regard to the equations and Ptolemy when he dealt with the declination of the Sun (Pingree 1970, p. 106). According to McCarthy and Byrne, Khwārizmī's original handbook juxtaposed tables, which addressed the same kind of tasks, but came from different cultural origins. Examples illustrating the diverse components in the extant texts and tables and their modifications are the replacement of the Yazdagird calendar by the Hijra era, the addition of calendars alien to the traditions in India such as the ancient Egyptian, Seleucid, Roman, and Christian eras, the use of theorems (such as the Menelaus theorem) that were unknown to Hindu astronomers, the use of the value for the obliquity of the ecliptic as found in Ptolemy's *Handy Tables*, the use of the Ptolemaic value of 66⅔ miles for a terrestrial degree, and the replacement of the latitude of Baghdad by the latitude of Cordova (Neugebauer, p. 19; Kennedy and Janjanian, pp. 73, 77; Goldstein 1967, pp. 7–8; Van Dalen, 1996, pp. 196, 240).

Khwārizmī's treatise on the Jewish calendar gives rules for determining the mean longitude of the Sun and the Moon based on this calendar and for determining on what day of the Muslim week the first day of the New Year shall fall. It also discusses the 19-year intercalation cycle and the temporal distance between the beginning of the Jewish era, *i. e.*, the creation of Adam and the beginning of the Seleucid era (Kennedy, 1964, pp. 55–59; Toomer, p. 360). The treatise on how to work with an astrolabe is only fragmentarily preserved, and opinions vary as to whether these fragments in their present-form represent the genuine version of what Khwārizmī actually wrote. The treatise on how to construct an astrolabe seems to be lost. Khwārizmī's book on geography *Kitāb Ṣūrat al-arḍ* combines substantial parts of Ptolemy's *Geography* with many non-Ptolemaic coordinates and place names. His two writings on arithmetic, one in the tradition of oral reckoning and the other according to the Indian tradition of written reckoning using the decimal place-value system, are lost in Arabic. The latter is extant in various Latin manuscripts. Khwārizmī's book on algebra is the first known in Arabic. It treats quadratic equations, the measurement of areas and volumes, commercial problems by means of four proportional quantities, and several types of Muslim inheritance mathematics. This text too was translated into Latin by at least two translators. Its influence upon elementary algebra in Arabic, Persian, Ottoman Turkish, Latin, and European vernacular languages was substantial.

Finally, it is worth mentioning that Khwarizmi may have participated in a number of scientific expeditions, one to measure the size of the Earth, the other to explore the regions north of the Caspian Sea (Matvievskaya and Rozenfeld, 1983, Vol. 2: p.41). The first, though, has been recently questioned (King, 2000).

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Kidinnu [Kidin, Kidenas]

Flourished **(Iraq), 4th century BCE**

Kidinnu was a Babylonian astronomer known as Kidenas by the Greeks. He was clearly an astronomer of repute in the ancient world, for he was mentioned in **Pliny**'s *Natural History* in the 1st century and his computation of lunar eclipses was used by the 2nd-century Greek astrologer Vettius Valens in his astrological compendium, the *Anthology*. Kidinnu became the focus of a modern controversy in 1923 when he was credited by the cuneiform scholar P. Schnabel with the discovery of the precession of the equinoxes prior to **Hipparchus**, along with System B for calculating the Moon's position in 314 BCE. Criticism by F. X. Kugler prompted Schnabel to revise the date to 379 BCE, but **Otto Neugebauer** decisively disproved Schnabel's thesis in 1950.

Nicholas Campion

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Neugebauer, Otto (1975). *A History of Ancient Mathematical Astronomy*. 3 pts. New York: Springer-Verlag.

Kienle, Hans Georg

Born **Kulmbach, Bavaria, Germany, 22 October 1895**
Died **Heidelberg, Baden-Württemberg, (Germany), 15 February 1975**

Stellar spectroscopist Hans Kienle had the distinction of running four major German observatories: He succeeded director **Johannes Hartmann** at Göttingen and then went on to directorships at Potsdam, of the Astrophysical Observatory of the German Academy of Science, and at Heidelberg. With **Ludwig Biermann,** he also superintended the Copenhagen Observatory during the Nazi occupation. Kienle was **Martin Schwarzschild**'s thesis advisor.

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Kiepenheuer, Karl-Otto

Born **Weimar, Germany, 10 November 1910**
Died **Ensenada, Mexico, 23 May 1975**

Along with **Erich Regener**, German solar physicist Karl-Otto Kiepenheuer undertook the first balloon-borne ultraviolet observations of the Sun, in 1939. An early investigator in the new field of solar magnetohydrodynamics, he also was the first to invoke synchrotron radiation as an astrophysical process.

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Kiess, Carl Clarence

Born **Fort Wayne, Indiana, USA, 18 October 1887**
Died **probably Washington, DC, USA, 16 October 1967**

Carl Kiess conducted spectroscopic measurements in the laboratory to enhance investigations of solar and stellar spectra. He was born to John F. and Florence Fordney Kiess, and was married on 21 June 1919 to Harriet Knudsen, with whom he had a daughter, Margaret, the following year.

In 1906, Kiess began his studies at Indiana University in Bloomington, where he received his BA in astronomy with high distinction in 1910. He earned a Ph.D. in 1913 from the University of California at Berkeley, where he was a fellow at the Lick Observatory and a student of **William Campbell**. Kiess taught at the University of Missouri, Pomona College, and the University of Michigan before taking a position in 1917 as a physicist at the United States National Bureau of Standards [NBS] in Washington, DC. There, he worked alongside William F. Meggers, section chief of the Spectroscopy Section, to produce numerous books and papers on spectroscopic measurements. Kiess taught in the NBS postgraduate school, and gave courses at Georgetown University and George Washington University as well. He wrote about a 100 scientific papers in his fields of research prior to retiring from the NBS on 31 October 1957.

In addition to his extensive laboratory work, Kiess participated as a government scientist on expeditions to observe eclipses in Brazil. He spent several weeks at an observation post near the summit of Mauana Loa, Hawaii, accompanied by C. H. Corliss, another NBS spectroscopist. Their analysis of sunlight reflected from Mars showed no evidence of water vapor or oxygen in its atmosphere. His collaboration with C. J. Humphreys during World War II determined the electronic configuration of atomic uranium, thereby establishing for the first time the existence of a second series of rare-earth elements. Kiess's work on silicon atoms enabled him to identify conspicuous solar spectral lines that had long resisted identification. As a result of his laboratory studies on the phosphorus atom, this element was first detected in the Sun's atmosphere. Kiess also collaborated with the Allegheny Observatory on measurements of solar spectral lines.

Kiess held memberships in the American Astronomical Society, American Physical Society, Astronomical Society of the Pacific, American Association for the Advancement of Science, Washington Academy of Science, Optical Society of America, and National Geographic Society. Kiess was awarded the Donohoe Comet Medal of the Astronomical Society of the Pacific in 1911 for his discovery of a comet (C/1911 N1). In 1946, he received the Department of Commerce Meritorious Service Award. Nine years later, Kiess was awarded the department's Exceptional Service Award for his outstanding achievements in spectroscopy, including the discovery of atomic energy levels in highly complex atoms, his precise measurements of spectral wavelengths, and for basic contributions to astrophysics. On 7 October 1967, he received the Vicennial Medal for his 20 years of service on the faculty of Georgetown University. Kiess is honored with an honorary degree from Indiana University (D.Sc., 1963), an asteroid ((1788) Kiess), and a lunar crater (named in his honor in 1973).

Marvin Bolt

Selected Reference

Poggendorff, J. C. (1937). "Kiess." In *Biographisch-literarisches Handwörterbuch*. Vol. 6, p. 1314. Berlin.

Kimura, Hisashi

Born **Kanazawa, Ishikawa Prefecture, Japan, 10 September 1870**
Died **probably Kanazawa, Ishikawa Prefecture, Japan, 26 September 1943**

Hisashi Kimura observed terrestrial latitudinal variations and developed an equation to account for it. He was adopted into the family Kimura. In 1892, he graduated from the Department of Astronomy in the College of Science, Imperial University of Tokyo. Kimura then worked in the Tokyo Astronomical Observatory, and in 1899 became the first director of Mizusawa Latitude Observatory, established when the International Latitude Service [ILS] started. The ILS comprised six stations (including Mizusawa) on a circle of constant latitude around the world; its purpose was to study the fluctuating motion of the position of the Earth's pole.

This fluctuation should be expressible by using two terms if the Earth is a rigid body. However, the actual latitude variation observed at all ILS stations showed unexpectedly complicated time variations. Kimura reported in 1902 that the observed latitude variations are better expressed by means of an equation with three terms. The introduced third term (now often called the Kimura term) was shown to be common to all stations and independent of the pole's motion. The term shows a seasonal variation with an amplitude range less than 0.5″, with a maximum in winter and a minimum in summer.

Kimura's original 1902 note was published in both the *Astronomical Journal* and the *Astronomische Nachrichten*. Although it is now thought that the Kimura term is due to the presence of a liquid core in the Earth's interior, we have still much to study to understand its real origin.

Kimura received various prizes, such as the Gold Medal from the Royal Society, the First Prize from the Japanese Academy, and many others. A crater on the farside of the Moon was named Kimura to honor his scientific contribution.

Naoshi Fukushima

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Kindī: Abū Yūsuf Yaʿqūb ibn Isḥāq al-Kindī

Born **probably Kūfa, (Iraq), *circa* 800**
Died **probably Baghdad, (Iraq), after 870**

Kindī was a pivotal figure in the transmission of Greek science into the Islamic world. A polymath, he left approximately 260 treatises on various scientific and philosophical subjects, including optics, astronomy, arithmetic, geometry, medicine, music, and metaphysics. Only a few of these have survived. Little is known about his life.

Kindī arrived in Baghdad, the capital of the Islamic realm, during the reign of the ʿAbbāsid Caliph **Ma'mūn** (reigned: 813–833), when the Graeco–Arabic translation movement was in its early stages. Kindī enjoyed the favor of several caliphs, serving as tutor to the son of Caliph Muʿtaṣim (reigned: 833–842), under whom Kindī especially flourished, but he fell into disgrace under Caliph Mutawakkil (reigned: 847–861). His library was confiscated, and he was publicly beaten, possibly due to court intrigue. According to some accounts, Kindī's library was eventually restored.

Although he is remembered primarily as "the philosopher of the Arabs," Kindī was active in many areas of scientific research. His work is significant in the history of astronomy for a number of reasons. First, he founded the philosophical program of study, centering on the works of **Aristotle**, without which the pursuit of Greek-inspired astronomy, and the many contributions made by Islamic theoretical astronomers, would have been impossible. He taught that philosophical knowledge can be acquired only through years of sustained study. The sciences of the quadrivium (arithmetic, geometry, music, and astronomy) must be mastered before the student can understand Aristotle's writings on logic, physics, ethics, and metaphysics, or other sciences such as astrology and medicine. Kindī's approach toward the ancient sciences was to complete them, and his strategy of presentation was to combine observation with the Euclidean "axiomatic method" of rational demonstration, a perspective he presented in a treatise entitled *That Philosophy Can Be Acquired Only by Mathematical Discipline.* Kindī did not slavishly follow Aristotle or other Greek philosophers. For example, he produced an ingenious argument against the infinite magnitude of the Universe; by employing a skillful *reductio ad absurdum* argument, Kindī showed how the notion of actual infinity leads to paradoxes.

Second, Kindī began the systematic formulation of a scientific Arabic terminology based on Greek concepts. This idiom formed the groundwork for the later philosophical and scientific contributions of **Fārābī**, **Ibn Sīnā**, Ghazālī, **Ibn Rushd**, and others. And through Latin translations of the 12th century, Kindī's influence also extended into Europe.

Third, Kindī also created an Islamic idiom, showing how Greek ideas could be adapted into the Islamic metaphysical framework, without detriment to either. Despite these efforts, however, Kindī clashed with contemporary Islamic theologians, who often viewed the Greek sciences with suspicion.

In terms of actual work in astronomy and cosmology, Sezgin lists some 30 works, only 13 or so being extant. Of those that are extant, five are general or cosmological works (one being a paraphrase of the *Almagest*), three concern instruments, and the rest are on particular topics. None of these seem particularly original but indicate an interest in making the Greek scientific heritage better known to a wider audience. Kindī also wrote extensively on astrological topics and was responsible for introducing **Abū Maʿshar** to astrology; he was to become the most influential astrological authority in both the Arabic and the Latin Middle Ages. Finally, it is worth mentioning that Kindī was also interested in optics, a subject important to astronomy, and developed a new analytical approach, punctiform analysis, whereby each point of the visible object is perceived by an individual ray coming from the eye.

Glen M. Cooper

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Walzer, R. (1957). "New Studies on al-Kindi." *Oriens* 10: 203–232. (Excellent summary of the then available treatises by Kindī.)

King, William Frederick

Born **Stowmarket, Suffolk, England, 19 February 1854**
Died **Ottawa, Ontario, Canada, 23 April 1916**

As Canada's first chief astronomer, William King founded the Dominion Observatory and oversaw the creation of the Dominion Astrophysical Observatory. The son of William King and Ellen Archer, he married Augusta Florence Snow in 1881. The couple had four sons and two daughters.

King arrived in Canada at the age of eight, studying at the Port Hope Grammar School and later at the University of Toronto, which he entered in 1869. King left the university in September 1872 without a degree to take a position as subassistant astronomer to the British team of the International Boundary Survey in western Canada. On completion of the work, he returned to Toronto in 1874 to finish his degree, with a gold medal in mathematics.

Two years later, after passing the examinations for the designation of Dominion Land Surveyor and Dominion Topographical Surveyor, King joined the Department of the Interior's surveying team in the interior plains. Some of his astronomical work employed the telegraph. King rose quickly through the ranks; by 1886, he was chief inspector of surveys and moved to Ottawa to work directly with the surveyor-general. In 1890, King became chief astronomer. With **Otto Klotz**, he built a small observatory in the capital, and the two worked to persuade the government to create a national observatory. By 1899, the way was clear politically, and the Dominion Observatory opened in 1905. King became its director as well as its chief astronomer.

From 1892, King was the International Boundary Commissioner for Canada. In 1909, when the Geodetic Survey of Canada was created, he became its director as well. King strongly supported his junior associate, **John Plaskett**, in lobbying for what became the Dominion Astrophysical Observatory.

King was active in the Royal Astronomical Society of Canada and the American Astronomical Society. The latter's first meeting outside the United States was held in Ottawa in 1911 at King's invitation. He was elected a fellow of the Royal Society of Canada and served as its president in 1911. King was awarded an honorary doctorate from the University of Toronto. He was also elected a Companion of the Order of Saint Michael and Saint George [CMG], a step below knighthood.

King's scientific work was limited to astronomical surveying. His importance to Canadian astronomy was his ability to create two national observatories in a small, scientifically backward nation within 15 years.

Richard A. Jarrell

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Kirch, Christfried

Born **Guben, (Brandenburg, Germany), 24 December 1694**
Died **Berlin, (Germany), 9 March 1740**

From 1716 to 1740 Christfried Kirch worked as an astronomer and calendar maker at the observatory of the Academy of Sciences in Berlin. The son of the astronomer **Gottfried Kirch** and his second wife, **Maria Kirch**, Christfried Kirch received a careful education in Berlin. Until 1712, he was a student at the Joachimsthalsche Gymnasium. He continued his studies for 2 years at Nuremberg, and later at Leipzig and Königsberg. In 1715, Christfried Kirch joined his mother in her move to Danzig, where he worked for 18 months at the observatory of the late **Johannes Hevel**. From childhood on he was trained by his parents in astronomical matters. By the age of 20, Christfried Kirch started to publish annual planetary ephemerides.

Having shown sunspots and other celestial phenomena to Tsar Peter the Great of Russia at the Danzig Observatory, Christfried Kirch and his mother received an offer to work as astronomers at Moscow. This offer was declined, mainly because a career for Christfried Kirch at Berlin was already very probable and preferred by both of them. Also later, Christfried Kirch received some offers to work at the Academy of Sciences in Saint Petersburg, which he never accepted.

After the death of the Berlin astronomer Johann Heinrich Hoffmann in April 1716, Christfried Kirch accepted the offer of a permanent position in astronomy at the Academy of Sciences in Berlin. He became a member of the Academy of Sciences in October 1716, and got one of the two positions of an *observator* (observer) at the observatory of the academy in January 1717. In 1728, Christfried Kirch was promoted from the position of an "observer" to that of the regular "astronomer" of the Academy of Sciences.

As was usual for the Berlin astronomers of that time, the main task of Christfried Kirch was the preparation of the annual calendar issued by the academy. In this task, he was supported unofficially by his mother and by his sister, **Christine Kirch**. In addition to Christfried Kirch's calendar work he published planetary ephemerides and carried out astronomical observations at the observatory. His observations concerned nearly all astronomical phenomena. In particular, Christfried Kirch observed the transit of Mercury in 1720 and the solar eclipse in 1733. From eclipses of Jupiter's satellites, he derived the differences in longitude between Berlin, Paris, and Saint Petersburg. In general, with regard to work, Christfried Kirch followed closely in the lines of his father. He was elected as a foreign member of the French Academy of Sciences (Paris) in 1723 and of the Royal Academy (London) in 1742 (after his death).

Christfried Kirch was very careful in all his work and had an intense correspondence with most of the eminent astronomers of his time. He lived together with his sisters, and was never married. Christfried Kirch died of a heart attack.

Roland Wielen

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Schröder, Hans (1851). "Lexikon der hamburgischen Schriftsteller bis zur Gegenwart." Hamburg: Perthes-Besser und Mauke. (For the relation of J. E. Bode to the Kirch family, see "Bode, J. E.", Vol. 1, p. 284.)

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Wolf, Rudolf (1877). *Geschichte der Astronomie*. München: Verlag R. Oldenbourg. (For the Kirch family, see pp. 457–459.)

Kirch, Christine

Born **Guben, (Germany), *circa* 1696**
Died **Berlin, (Germany), 6 May 1782**

Christine Kirch worked mainly in the background and supported her father, her mother, her brother, and later other astronomers at Berlin in calculating calendars and in carrying out astronomical observations. The daughter of the astronomer **Gottfried Kirch** and his second wife, **Maria Kirch**, and the sister of the astronomer **Christfried Kirch**, Christine Kirch was educated in astronomy by her parents. She assisted them in their astronomical observations during her childhood. It is reported that Christine Kirch, as a child, was mainly responsible for taking the time (or measuring time intervals by using a pendulum). When she was older, she was introduced to calendar making. Christine Kirch assisted first her mother and later her brother in calculating various calendars. Until 1740, she did not receive a regular salary for her contributions, but only occasionally small donations from the Berlin Academy of Sciences. After the death of Christfried, the academy had to rely more strongly on Christine Kirch's help in calculating calendars. She became especially responsible for preparing the calendar for Silesia, the province conquered for Prussia in 1740–1742 by Friedrich the Great. The new, populous province significantly increased the income of the Berlin Academy from the academy monopoly on calendars in Prussia. In 1776, Christine Kirch received the very respectable salary of 400 Thaler from the Academy.

Christine Kirch continued her esteemed calendar work up to her old age. When she was 77 years old, the academy put her into a status that we would nowadays describe as "emeritus": she continued to receive her salary but no longer had an obligation to work. Instead, she was to introduce the new Berlin astronomer **Johann Bode** to calendar making. Her contacts with Bode were quite friendly, and were probably strongly enhanced by the fact that in

1774 Bode married a grandniece of Christine Kirch. After the death of his first wife in 1782, Bode even married in 1783 another grandniece of Christine Kirch (the older sister of his first wife).

In a letter to Christine Kirch, the academy expressed explicitly its official thanks for her work on calendars. She died as a very respected person.

The youngest sister of Christine Kirch, Margaretha Kirch, was also active in astronomy, but we know only very few details about her life. She was seven when her father died. Later, she observed comets, especially the comet 1743 C1, which was discovered by Augustin Grischow in Berlin on 10 February 1743.

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Kirch, Gottfried

Born **Guben, (Bradenburg, Germany), 18 December 1639**
Died **Berlin, (Germany), 25 July 1710**

Gottfried Kirch, probably the most prominent German astronomer around 1700, is best known for having published long series of calendars and ephemerides. Also an active observer, Kirch was famous for his discovery of the bright comet of 1680. In 1686 Kirch detected the variable star χ Cygni, the third known variable star after Mira itself (detected 1639) and Algol (1669). His career culminated in his appointment as the first permanently engaged *astronomo ordinario* at Berlin on 18 May 1700.

Kirch was born during the Thirty Years' War. His father, Michael Kirch, a tailor, had to flee with his family from Guben, and the childhood of Gottfried was therefore rather restless. He probably never received a university degree. However, Kirch had good contacts with **Erhard Weigel**, who taught mathematics, astronomy, geography, and physics at the University of Jena from 1653 to 1699. Weigel recommended Kirch to the prominent astronomer **Johann Hevel**, who had a well-equipped private observatory at Danzig. In 1674, Kirch worked there for some months.

Before 1700 Kirch's living conditions were rather unstable and his income not safe. While he probably earned most of his money as a calendar maker, he also worked as a teacher. Kirch lived in Guben, in Langgrün, Thuringia, until 1676, in Leipzig Saxony 1676–1680, in Coburg 1680–1681, again in Leipzig 1681–1692 and in Guben 1692–1700, and finally in Berlin 1700–1710.

At Langgrün, Kirch married Maria Lang in 1667; they had seven sons and one daughter. Maria Kirch died in 1690. In 1692 he married his second wife, Maria Margaretha Winkelmann, and they had five daughters and two sons. His second wife supported him strongly in calculating calendars and in carrying out astronomical and meteorological observations. **Maria Kirch** became widely known as the "Kirchin," *i. e.*, the "feminine version" of the name Kirch. Also, many of their children supported and followed them in their astronomical tasks, especially **Christfried Kirch** and **Christine Kirch**.

From 1663 until his death, Gottfried Kirch carried out astronomical observations quite regularly, usually using small instruments. His observations concerned nearly all types of celestial objects or phenomena, from sunspots to comets to variable stars. In 1678, he published a paper on Mira, based partially on his own observations of this variable star. Kirch became most famous as the discoverer of the extremely bright comet of 1680, now designated C/1680 V1. This was the first telescopic comet discovery in history. In 1681, Kirch described the galactic open star cluster that is now designated as Messier 11. In 1686, he found χ Cygni to be a variable star and determined its period as 404.5 days.

The main astronomical activity of Kirch was, however, the computation and editing of calendars for the general public and the publishing of astronomical ephemerides. His first calendars appeared in 1667 in Jena and Helmstedt, later in Nuremberg and Königsberg, *e. g.*, the "Christen-, Jüden- und Türcken-Kalender oder alt und neu Jahr-Buch," and the "Alter und neuer Schreib-Kalender in Cantzeleyen, Aemptern, Raths-und Richter-Stuben … nützlich zu gebrauchen." Kirch's ephemerides (*e. g.*, *Ephemeridum Motuum Coelestium*), first published in 1681, are mainly based on **Johannes Kepler**'s Rudolphine Tables, but Kirch added some corrections.

In 1700, Kirch accepted the call to the permanent position as the *astronomo ordinario* at Berlin. This position was created by Friedrich III, Elector of Brandenburg, in his edict of 10 May 1700, the so called *Kalenderpatent*. This edict followed the decision of the German Protestant states in 1699 to introduce from 1700 onward a new "improved" calendar, which was essentially identical to the Catholic Gregorian Calendar (except for the computation of the date of Easter) and which should be calculated by qualified astronomers. The edict introduced a monopoly for this calendar in the Electorate of Brandenburg (later in Prussia) and imposed a "calendar tax." The corresponding income was used for paying the astronomer and other members of the Berlin Academy of Sciences, which was founded on 11 July 1700. Friedrich III promised also to erect an observatory at Berlin, but this observatory was not actually inaugurated until 19 January 1711.

Kirch started his expected calendar work immediately and in 1700 was able to prepare the first calendar of this series, the "Chur-Brandenburgischer Verbesserter Calender Auff das Jahr Christi 1701." In his calendar work Kirch was strongly supported by his wife Maria Margaretha Kirch and by an assistant astronomer, Johann Heinrich Hoffmann (1669–1716), who followed Kirch as *astronomo ordinario* after Kirch's death in 1710. The Berlin calendars were quite popular and certainly gained much from Kirch's long experience in calculating and editing calendars. His calendar experience was also the strongest motivation for calling him to the position of the astronomer at Berlin, in spite of his advanced age of 60 years.

The observing conditions at Berlin were not the best. Kirch had to use small transportable instruments, located either in his own house or (after 1708) in the tower of the unfinished Berlin Observatory. After 1705, he was sometimes allowed to use the better-equipped private observatory of Baron Bernhard Friedrich von Krosigk (1656–1714). Nevertheless, Kirch also collected and published many astronomical observations at Berlin. For example, he discovered in 1702 the globular cluster that is now designated as Messier 5, and his wife and he were among the independent discoverers of comet C/1702 H1.

After his death, his calendar work was continued (somewhat unofficially) by Maria Margaretha, officially by Hoffmann from 1710 to 1716, and then by his son, Christfried, from 1716 onward, and then again unofficially by his daughter Christine. We should remark here that the prominent Berlin astronomer **Johann Bode** had strong personal links to the Kirch family: Bode's first two wives were grandnieces of Christine, and hence great granddaughters of Kirch. Thus, Kirch established what is probably the longest family tradition in calendar and ephemerides making.

Two astronomical objects are named for Kirch: A lunar crater Kirch and the minor planet (6841) Gottfriedkirch.

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Kirch, Maria Margaretha Winkelman

Born **Panitzsch near Leipzig, (Germany), 25 February 1670**
Died **Berlin, (Germany), 29 December 1720**

Maria Margaretha Kirch was one of the few women active in astronomy around 1700. She was the second wife of the astronomer **Gottfried Kirch**, and the mother of the astronomers **Christfried Kirch** and **Christine Kirch**. While mainly engaged in calculating calendars, together with her husband and later her son, Maria Margaretha Kirch also carried out astronomical and meteorological observations. She became well known as one of the discoverers of a comet in 1702.

Maria Margaretha Winkelmann was the daughter of a Lutheran minister. At the age of 13, she had already lost both her father and her mother. Maria Margaretha received her general education privately, first from her father and then from her brother-in-law, Justinus Toellner. Knowledge of astronomy was mainly provided to her by a farmer and well-known astronomer, Christoph Arnold, who lived nearby at Sommerfeld. Probably due to his contacts with Arnold and

Toellner, the astronomer Gottfried Kirch met Maria Margaretha. She married him on 8 May 1692. Gottfried found in her not only the new housewife for him and his children, but someone also able and very willing to help him in his astronomical observations and in calculating calendars. For her, it was a welcome chance to follow her astronomical interests. Gottfried and Maria Kirch had six children, two of whom (Christfried and Christine) also became astronomers.

After living at Leipzig and Guben, Saxony, for some years, the Kirch family moved in 1700 to Berlin, where Gottfried accepted the newly established position of the *astronomo ordinario*. His main task in Berlin was to compute and edit the new calendar, and Maria Margaretha supported him very strongly in this task. She also carried out astronomical observations, using usually small transportable instruments. Her most significant success was the independent discovery of comet C/1702 H1. Maria Margaretha Kirch's husband confirmed her discovery; hence he is often also considered as one of the independent discoverers of this comet.

Maria Margaretha Kirch published three tracts between 1709 and 1711, but these publications were essentially of an astrological nature. Her other works, especially her calendar calculations and her observations, were usually contained in publications of her husband or her son.

After Gottfried's death, it was clear to Maria Margaretha that she had no chance to replace her husband in the official position of the *astronomo ordinario* at the Berlin Academy of Sciences. She asked, however, in August 1710 and in subsequent letters to the academy, for a minor position in order to continue her work for the calendar. In 1712, all Maria Margaretha Kirch's requests were finally rejected, although the president of the academy, **Gottfried Leibniz**, expressed explicitly his admiration for her astronomical skills. In 1711, Johann Heinrich Hoffmann (1669–1716) was officially appointed as the successor to her husband as astronomer of the academy.

In October 1712 Maria Margaretha moved with her children to the private observatory of Baron Bernhard Friedrich von Krosigk (1656–1714) at Berlin. There she carried out astronomical observations and continued her calendar work, which was published in Breslau and Nuremberg. After the death of Krosigk, Maria Margaretha moved to Danzig and reorganized and used the observatory of the deceased astronomer **Johannes Hevel**. In 1716, she declined an offer from Tsar Peter the Great of Russia for her and Christfried to become astronomers in Moscow.

Maria Margaretha returned to Berlin when Christfried was appointed (together with J. H. Wagner) as an astronomer of the Berlin academy in October 1716, after the death of Hoffmann. Back at Berlin, she supported her son in calculating the official calendar, as she had done earlier for her husband. In addition, Maria Margaretha earned money by providing the astronomical data for other calendars, including those issued at Dresden and in Hungary. Initially, she also used the Berlin Observatory for astronomical observations. However, the academy complained about the "visibility" of Maria Margaretha Kirch at the observatory and about her meddling with matters of the academy. In 1717, the Academy forced her to leave her home and the observatory. Maria Margaretha Kirch died of fever.

The minor planet (9815) Mariakirch has been named for Maria Margaretha Kirch.

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Kircher, Athanasius

Born **Geisa, (Hessen, Germany), 2 May 1598**
Died **Rome, (Italy), 27 November 1680**

Athanasius Kircher's greatest contribution was to sum up, through his 41 massive books, what had been achieved in a given subject by past scientists and what scientific methods seemed most appropriate for future study. The son of Johannes Kircher and

Anna Gansek, he received his early schooling at the Jesuit school in Fulda, after which he entered the Jesuit Order in 1616. Kircher studied rhetoric, philosophy, and mathematics at the University of Paderborn and later at the University of Cologne. He then studied theology in Mainz. It was there that Kircher first used a telescope to study sunspots. He became a professor of mathematics, philosophy, and oriental languages at the University of Würzburg, and then was appointed professor of mathematics at the Roman College.

In 1656 Kircher published *Iter Celeste*, a treatise on astronomy emphasizing fixed and movable stars as well as the composition and structure of these bodies. He gradually became skilled in constructing telescopes; his chief interest was in comets and in eclipses (both solar and lunar). He was the first to give a clear depiction of Jupiter and Saturn. Kircher's greatest contribution to astronomy, however, was providing a clearinghouse of astronomical data and discoveries; he provided a good number of astronomers with valuable information, having been a correspondent with most important astronomers of the time.

Kircher also studied optics and horology, which included not only sundials but also clocks powered by the regularity of certain plants, such as the sunflower. Kircher's contributions to mathematics, astronomy, harmonics, acoustics, chemistry, microscopy, and medicine played a significant part in early scientific revolution. In his works, he displayed an understanding of the sciences of the past, but he was always open to the developments and possibilities of the future. His *Museum Kircherianum* was considered one of the best science museums in the world. So broad and so well known were his interests that Kircher was the recipient of many scientific curiosities from other scientists. For three centuries it has survived in Rome. Recently, the scientific items of this museum have been divided up and spread throughout three other Roman museums.

Among Kircher's inventions are found the megaphone, the pantometrum for solving geometrical problems, and a counting machine. His discoveries include sea phosphorescence as well as microscopically small organisms, the nature of which remains disputed. Kircher's works were quoted by many scholars of the day. It was by facilitating a wide diffusion of knowledge, by stimulating thought and discussion about his vast collections of scientific information, that Kircher earned a place among the fathers of modern science and the title of *universal genius.*

Kircher wrote about the Coptic language and showed that it was a vestige of early Egyptian. He was the first to have discovered the phonetic value of a hieroglyph. His interest in interpreting the obelisks led him to such a thorough study of the subject that princes, popes, and cardinals appointed Kircher to decipher various obelisks. He has been called the real founder of Egyptology.

Kircher developed a great interest in the underworld and assumed the existence of huge underground reservoirs. During the violent eruption of Mount Etna in 1630, he had himself lowered into the cone for closer observation. His two-volume work, *Mundus subterraneus* (Amsterdam, 1665), was probably the first printed work on geophysics and vulcanology. In it, he held that much of the phenomena on Earth, including the formation of minerals, were due to the fact that there was fire under the Earth's surface, an unusual teaching for those days. Some of his works were really encyclopedic in their scope. One such is *Phonurgia nova* (Kempten, 1673), which contains all the then-known mathematics and physics concerning sound as well as his own use of the megaphone. Another is the popular *Musurgia universalis* (Rome, 1646), one of Kircher's longest works, which marks a crucial juncture in the development of music.

Kircher's treatise on light, *Ars magna lucis et umbrae* (Rome, 1646), also discussed the planetary system. He showed no inclination to follow the heliocentric system, but favored **Tycho Brahe**'s model in which the planets circle the Sun. In *Iter Exstaticum* (1656) he recounted an imaginary voyage, guided by angels through Brahe's heavens. Despite his censors, Kircher believed in the existence of other worlds inhabited by creatures similar to humans, posing this as an example of God's omnipotence. Some other inventions found in this book include the magic lantern, the predecessor to the movies.

Joseph F. MacDonnell

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Kirchhoff, Gustav Robert

Born **Königsberg (Kaliningrad, Russia), 12 March 1824**
Died **Berlin, Germany, 17 October 1887**

Gustav Kirchhoff founded spectral analysis (with **Robert Bunsen**) and discovered fundamental properties of the absorption and emission of electromagnetic radiation. His father, a government law councillor, was devoted to the Prussian state and encouraged his sons to similarly serve the state to the best of their abilities. Kirchhoff

enrolled at the University of Königsberg, where he studied mathematical physics under Carl Gustav Jacob Jacobi (1804–1851) and Franz Ernst Neumann (1798–1895). After graduation in 1847 and a short scientific visit to Paris, he held an unsalaried lectureship in Berlin. In 1850, Kirchhoff was appointed extraordinary professor of physics at Breslau, where the arrival of Bunsen the following year inaugurated an immensely fruitful collaboration that would revolutionize astronomy. Kirchhoff moved to Heidelberg as professor of physics in 1854, following Bunsen who had gone there 2 years before.

In 1857, Kirchhoff married Clara Richelot, daughter of one of his former mathematics professors at Königsberg. This first marriage, which gave the couple four children, came to a premature end in 1869 with Clara's untimely death. These were difficult times for Kirchhoff, as he had just the year before suffered a debilitating injury to a foot, which left him having to use crutches or a wheelchair for extended periods of time thereafter. In 1872, he married Luise Brömmel, a childless union that remained happy to the end of his life.

Increasingly unable to pursue experimental work in view of his failing health, Kirchhoff moved to Berlin as professor of mathematical physics in 1875, the same year he was elected fellow of the Royal Society. Ill health finally forced him into retirement in 1886.

Kirchhoff was a mathematical physicist by training. He made his first important scientific contributions in 1845–1846, while still a student, by using topological concepts to generalize Ohm's law to complex networks of electrical conductors. In 1857, Kirchoff went on to demonstrate theoretically that an oscillating current would propagate in a conductor of zero resistance at the speed of light, an important step toward the electromagnetic theory of light, though he did not make that connection.

Kirchhoff's most important contribution to astronomy was his development of spectroscopic analysis with Bunsen and their subsequent determination of the chemical composition of the Sun. Half a century before quantum mechanics would provide for it a firm physical basis, Kirchhoff and Bunsen established spectroscopy as an empirical science. Between 1859 and 1861, they demonstrated that:

(1) incandescent solids or liquids emit continuous spectra;
(2) the spectra of heated gases consist of a number of bright lines, characterized by different wavelength patterns for different gases; and
(3) when the light from an incandescent gas or liquid traverses a heated gas, the gas absorbs light at the same wavelength is as it emits when heated to the same temperature.

This last principle in particular provided a natural explanation for the ubiquitous dark lines in the solar spectrum, first noted in 1802 by **William Wollaston** and studied in much greater detail in 1817 by **Joseph von Fraunhofer**.

Kirchhoff's next step was the production of a detailed map of the solar spectrum, in the course of which he ruined his eyesight to the extent that an assistant eventually had to complete the map. In a parallel effort involving the comparison of this growing map with laboratory spectra of gases, Kirchhoff began to determine the chemical composition of the Sun's atmosphere. He first identified the elements sodium, calcium, barium, strontium, magnesium, iron, nickel, copper, cobalt, and zinc, with the list steadily growing ever longer in the following years. Kirchhoff's spectroscopic findings also led him to put forth a theory of the Sun's physical constitution, whereby a hot gaseous atmosphere is assumed to overlie a hotter, incandescent liquid core. This stood in marked contrast to the still prevalent view promoted by **William Herschel** and **John Herschel** of a dark, cold solar nucleus; Kirchhoff's efforts contributed much to the latter concept's demise in the second half of the 19th century.

True to his training and inclination, Kirchhoff did not neglect theoretical aspects related to his work in spectroscopy. In 1859, as a consequence of his chemical spectral analysis, he had formulated a general principle stating that the ratio of emission to absorption of all material bodies is the same at a given temperature and wavelength. Kirchhoff's law in turn led to his formulation in 1862 of the concept of the perfect blackbody, of vital importance in the later development of quantum theory. Although in this he had been partly anticipated by others, perhaps most notably by the British physicist **Balfour Stewart**, the generality and mathematical rigor of Kirchhoff's work is such that he is now credited with the formulation of the blackbody concept.

Paul Charbonneau

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Kirkwood, Daniel

Born **Harford County, Maryland, USA, 27 September 1814**
Died **Riverside, California, USA, 11 June 1895**

Daniel Kirkwood's most important contribution to astronomy was his discovery, published in 1866, of gaps in the distribution of orbits of the asteroids. His interest in the origin and evolution of the Solar System was clearly evident in his books and papers on asteroids, comets, and meteors that were important contributions on these topics. Born in Bladensburgh, Maryland, to John Kirkwood, a farmer, and his wife Agnes (*née* Hope) Kirkwood, Daniel was the 12th of 13 children. His early education was limited to a nearby country school. Kirkwood began his career as a teacher at the age of 19 when he took a teaching position at a country school in Hopewell, Pennsylvania. He enrolled at the York County Academy, York, Pennsylvania, in 1834, majoring in mathematics. Following his graduation in 1838, Kirkwood was appointed first assistant and instructor in mathematics at the York County Academy. In 1843 he became principal of the Lancaster, Pennsylvania, High School, and in 1845 he married Sarah A. McNair.

Kirkwood became interested in the rotations of the planets in 1839, during his first year as instructor in mathematics at York County Academy. In August 1843 he derived a mathematical analogy relating the rotation and revolution periods of the planets based on the nebular hypothesis of **Pierre de Laplace**. A year later, he described his work to the eminent astronomer **Sears Walker**. At the Second Meeting of the American Association for the Advancement of Science [AAAS], at Cambridge, Massachusetts, in August 1849 Walker presented Kirkwood's letter, dated 4 July 1849, to the meeting as a formal paper. **Benjamin Gould** asserted that Kirkwood's analogy supported the Laplace nebular hypothesis, while Walker proclaimed it "the most important harmony in the Solar System discovered since the time of Kepler." Thus, Kirkwood's letter brought instant international fame to the 35-year-old principal of the Pottsville Academy. David Brewster called it "a work of genius" in his 1850 presidential address to the British Association for the Advancement of Science. The Kirkwood analogy became irrelevant when the Laplace nebular hypothesis was temporarily abondoned in favor of **Chambarlin-Moubton** hypothesis , but it is noteworthy that Kirkwood in his later years became one of the leading critics of Laplace's nebular hypothesis.

During his 5 years in Lancaster, Kirkwood published seven scholarly papers on astronomical topics including one in which he analyzed reports of a very bright meteor that had been seen in Maryland, Pennsylvania, New Jersey, Delaware, and Virginia on 13 July 1846. Kirkwood collected and compared "as many newspaper descriptions of the appearance as possible" and also "corresponded with scientific gentlemen residing in various parts of the country." Using this information he calculated a height of 62 miles, a track length of more than 200 miles, and a velocity of 13 miles/s. Kirkwood's efforts were reminiscent of a similar effort by **Nathaniel Bowditch** for the Weston, Connecticut meteorite observed widely all over New England in 1807. Both cases were valuable because too few such well-documented path observations and calculations had accumulated since the first coordinated attempts to determine meteor altitudes were made by **Johann Benzenberg** and **Heinrich Brandes** in Germany in 1798.

In 1849, Kirkwood accepted an appointment as the principal of the Pottsville Academy. Near the end of his second year in this position, Kirkwood gave some of the first public demonstrations of the Foucault pendulum in the United States. Kirkwood left the Pottsville Academy in 1851 to become professor of mathematics at Delaware College. He was elected by the faculty to be its president in 1854. After 2 years as president, he resigned to accept an appointment as professor of mathematics at Indiana University.

Kirkwood's interest in asteroids can be traced to the announcement of the discovery of minor planet (5) Astraea by **Karl Hencke** in Mareinwerder, Germany, in 1845. There had been no such discoveries after the first four asteroids were discovered between 1801 and 1807. Thus, the announcement of Hencke's discovery was a significant event, as was the announcement, 2 years later, of Hencke's second asteroid discovery (6) Hebe. At the time of the announcement of Hencke's first discovery, Kirkwood was principal of the Lancaster High School. Announcements of additional asteroid discoveries came in fairly rapid order, stimulating Kirkwood to study the orbits of this emerging new class of Solar System object. By 1857, a year after Kirkwood arrived on the Indiana campus, 55 asteroids with computed orbits were known to exist, and it was at about that time that Kirkwood first realized the existence of the gaps with which his name has since been associated. Kirkwood found an absence of asteroids with orbital periods that were 1/2, 1/3, 2/5, *etc.* of the orbital period of Jupiter.

Kirkwood formalized this most important of his contributions to Solar System astronomy at the AAAS meeting in 1866, in a paper that also dealt with a theory of meteors, and with the gaps in Saturn's rings. Kirkwood generalized the problem to some degree by noting that both the Cassini and Encke divisions in Saturn's rings would be populated with bodies with periods that would be in resonance with the periods of various Saturnian satellites.

Kirkwood's continued study of the asteroids led to several other important discoveries based on resonances of their orbital periods with that of Jupiter. This led to his prediction of the existence of what is now known as the Hilda group of asteroids at the two-thirds resonance. In 1892, Kirkwood identified some 32 other possible groups based on this concept.

Another aspect of Solar System dynamics that attracted Kirkwood's attention was the relationship between these various minor Solar System objects and other phenomena. He was the first to recognize and convincingly demonstrate that the orbits of certain periodic comets and those of certain meteor showers coincide and were likely related, a fact borne out in later studies. His speculations regarding a possible relationship between comets, asteroids, showers of meteors and stony meteorites and the origin of fireballs in asteroids were controversial but also productive.

Richard Proctor, a British astronomer and leading writer of popular books on astronomy, frequently called Kirkwood "the Kepler of our day" in his books. Proctor spoke in Indianapolis in 1873 while on a lecture tour of the United States. After the lecture he was approached by a delegation from Greencastle, Indiana, who requested that he lecture at DePauw University the next evening. Proctor replied, "No I cannot do so. I came from England to America to see Daniel Kirkwood. Tomorrow is my opportunity and I am going to Bloomington to see him."

Indiana University had a faculty of six in 1856, and this had increased to 23 in 1886, the year Kirkwood retired. He served under five presidents, including zoologist David Starr Jordan.

In 1889 Kirkwood and his wife moved to Riverside, California, where Mrs. Kirkwood died the next year. Their only child, Agnes, had died in 1874 after many years as an invalid. Shortly after their arrival in California, Kirkwood joined the Astronomical Society of the Pacific – unusual for the society at the time, given that he had performed the majority of his work outside California. He promptly published three papers in the *Publications of the Astronomical Society of the Pacific*, Volume II, followed by another in Volume III, and two more in Volume IV. David Starr Jordan became the founding president of Stanford University in 1891. He showed his high regard for Kirkwood by appointing him to the original Stanford Faculty as non-resident Professor and lecturer in astronomy. Kirkwood was then 77 years old.

Kirkwood was a prolific scholar, publishing a total of 133 papers and 3 books during his extended career. His last paper, about the Perseid meteors, was published in the *Sidereal Messenger* in April 1893, 2 years before his death. His body was returned to Bloomington a week after he died, and was buried at Rose Hill Cemetery on 17 June 1895, next to the graves of his wife and daughter. Kirkwood's funeral was an imposing event. Every business in town was closed for that period. The text of the funeral sermon read: "The heavens declare the Glory of God and the firmament showeth his handiwork." The minister said: "Dr. Kirkwood knew far more of the heavens than the writer of the eighth psalm."

Frank K. Edmondson

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Klein, Hermann Joseph

Born **Cologne, (Germany), 14 September 1844**
Died **Cologne, Germany, 1 July 1914**

The director of the Cologne Observatory during the late 19th and early 20th century, Hermann Klein was an energetic man of many talents renowned for an excellent star atlas, a map of the Milky Way, and several widely employed texts on astronomy and meteorology. But, above all else he was an ardent observer of the Moon, and his popular writings did much to advance the cause of lunar studies in Germany. As a young man, Klein had been personally acquainted with both **Johann von Mädler** and **Johann Schmidt**. He translated **James Nasmyth** and **John Carpenter**'s influential 1874 book *The Moon, Considered as a Planet, a World, and a Satellite* into German and fostered widespread interest in selenographical work in the periodicals he edited: *Sirius*, *Gaea*, *Wochenschrift für Astronomie*, and the annual *Jahrbuch für Astronomie und Geophysik*. Klein was undoubtedly the most active student of the Moon in Germany during the latter part of the 19th century.

Thomas A. Dobbins

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Klein, Oskar Benjamin

Born **Morby, Sweden, 15 September 1894**
Died **Stockholm, Sweden, 5 February 1977**

Swedish theoretical physicist Oskar Klein developed a useful extension of Theodor Kaluza's five-dimensional version of general relativity; Klein's work anticipates the existence of dark matter in the universe. The son of Austrian immigrants Gottleib Klein (The chief rabbi of Stockholm) and Toni Levy, Klein worked in the laboratory of **Svante Arrhenius** while still a teenager and earned a Ph.D. at Stockholm in 1921 with a study of suspensions and solutions. Klein worked briefly with **Niels Bohr** in Copenhagen and then with Svein Rosseland, using the initial ideas of quantum mechanics and the Bohr model of the atom to elucidate the process of collisional de-excitation (which is what prevents coronal lines from being observed in laboratory studies).

While at the University of Michigan from 1923 to 1935, Klein attempted to formulate a five-dimensional extension of general relativity that would incorporate electromagnetism as well as gravity. Theodore Kaluza attempted a similar unification at about the same time. The five-dimensional Kaluza–Klein space–time has applications in modern theoretical cosmology in that it implies a lowest-mass particle that preserves Kaluza–Klein symmetry and could be a dark matter candidate.

After returning to Europe, Klein was at Lund from 1925 to 1930 and professor at Stockholm from 1930 to his retirement in 1962. He contributed to a great many topics in quantum mechanics, but the next topic of importance for astronomy was his work with Yoshio Nishima of Japan, using the Dirac equation to study the scattering of light by electrons. The Klein–Nishina cross-section replaces the Thompson cross-section at high energies and is smaller. Toward the end of his life, Klein, together with **Hannes Alfvén**, proposed a cosmology that would be completely symmetric in matter and antimatter. He continued to take an active interest in cosmological issues well into the 1970s, corresponding with younger workers in the field like **John Wheeler**. Klein was awarded honorary degrees by the universities of Oslo and Copenhagen.

Virginia Trimble

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Klinkerfues, Ernst Friedrich Wilhelm

Born **Hofgeismar, (Hessen, Germany), 29 March 1827**
Died **probably Göttingen, Germany, 28 January 1884**

Textbook author Ernst F. W. Klinkerfues discovered eight comets and contributed to meteor theory. The son of Johann Reinhard and Sabine (*née* Dedolph) Klinkerfues, Ernst Klinkerfues was supported by relatives during a difficult youth. After school (gymnasium and polytechnic school) he worked as a surveyor with a railroad company.

From 1847 to 1851 Klinkerfues studied astronomy and mathematics in Marburg. In 1851, **Carl Gauss** accepted him as assistant at the Göttingen Observatory. After Gauss' death in 1855 the physicist Wilhelm Weber (1894–1891) was director of the observatory. Klinkerfues wrote his doctoral thesis on "A New Method to Calculate the Orbits of Binary Stars" and received his doctoral honors in 1855. Klinkerfues discovered or codiscovered eight comets in the years 1853–1863. His work was not only on astronomy, but also on meteorological themes. In addition to other instruments, Klinkerfues constructed a hygrometer. Klinkerfues published several texts. His main work, *Theoretische Astronomie*, was first printed in 1871; in it, he introduced the term meteor-shower radiant. Klinkerfues was a fellow of the Royal Astronomical Society (1882).

From 1861 on Klinkerfues was responsible for the observatory; from 1868 he was head of the department for practical astronomy, while the mathematician E. Schering led the theoretical department. Thus, Klinkerfues never reached his aim to be fully in charge of the astronomical work at Göttingen. Financial difficulties, health problems, and the struggle for the leading position in astronomy at Göttingen Observatory took its toll: Klinkerfues committed suicide.

Christof A. Plicht

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Klotz, Otto Julius

Born **Preston, (Cambridge, Ontario, Canada), 31 March 1852**
Died **Ottawa, Ontario, Canada, 28 December 1923**

Otto Klotz pioneered the development of geophysics in Canada. The son of German immigrants Otto and Elisé (*née* Wilhelm) Klotz, Otto studied at the local grammar school and entered the University of Toronto in 1869 but transferred to the University of Michigan the following year. There he studied with James Craig Watson at the Detroit Observatory. After graduating as a civil engineer in 1872, Klotz returned to Preston to establish a private surveying practice. After obtaining the highest qualifications in surveying, he became a contract surveyor for the Department of the Interior (1879), working on the prairie surveys. In 1885, the department gave him the more difficult task of surveying the Canadian Pacific Railway line through the mountains of British Columbia. In 1892, Klotz moved to Ottawa to become a permanent staff member. With the Chief Astronomer, **William King**, Klotz helped to press for, and then design, the future Dominion Observatory, which opened in Ottawa in 1905. Klotz was effectively the assistant director and headed the geophysical work at the observatory. On King's death in 1916, Klotz's appointment as director was held up due to anti-German sentiment. He became chief astronomer and director in 1917, serving till his death.

Klotz was active in the Royal Astronomical Society of Canada, a fellow of the Royal Society of Canada, and recipient of honorary degrees from the universities of Toronto, Michigan, and Pittsburgh. He was Canada's organizing head for entering both the International Union for Geodesy and Geophysics and the International Astronomical Union in 1919–1922. He was also president of the Seismological Society of America. Klotz and his wife Marie Widenmann (married 1873) had four children.

Klotz can be considered Canada's pioneer geophysicist. His division at the Dominion Observatory produced important results for decades after his death. He worked on gravity measurements and magnetic field surveys, but was most interested in the new field of seismology, working on microseisms. At the time of his death, the Dominion Observatory was one of the most important seismological stations in the world.

Richard A. Jarrell

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Klumpke Roberts, Dorothea

Born **San Francisco, California, USA, 9 August 1861**
Died **San Francisco, California, USA, 5 October 1942**

Dorothea Klumpke Roberts headed the Paris Observatory's Bureau of Measurements for the *Carte du Ciel* project, and also published the photographic *Isaac Roberts Atlas of 52 Regions.*

Dorothea Klumpke and her four sisters (all of whom became distinguished in their own fields) were educated in California and then in Paris. She received a BS in mathematics and mathematical astronomy from the University of Paris in 1886, and in 1893 became the first woman to receive the degree Doctor of Science there. Her dissertation was a mathematical study of the rings of Saturn.

In 1887, Klumpke began work at the Paris Observatory, measuring star positions on photographic plates. When the Paris Observatory was assigned a large section of the sky to be photographed for the *Carte du Ciel* project, she was appointed to head the Bureau of Measurements, and from 1891 to 1901 she carried out this task so well that she was awarded the first Prix des Dames of the Société Astronomique de France (1889) and Officier of the Paris Academy of Sciences in 1893.

In 1901 Klumpke married **Isaac Roberts**, an amateur astronomer and pioneer in astronomical photography. They settled in England, and she assisted him in his work. After Roberts' death in 1904, she returned to France and lived with her mother and sister, continuing Roberts' work and publishing results from time to time. In 1929 she published the *Isaac Roberts Atlas of 52 Regions, a Guide to William Herschel's Fields of Nebulosity*, followed by a 1932 supplement; these contained fine enlargements of 50 photographs from Roberts' collection. This earned her the Hélène-Paul Helbronner Prize from the French Academy of Sciences in 1932. In 1934 she was elected Chevalier of the Legion of Honor in recognition of 48 years of service to French astronomy.

About this time, Klumpke Roberts retired from active work, and returned to San Francisco, where she continued her interest in astronomy and young astronomers. She endowed several prizes through the Paris Observatory and the University of California, and gave money to the Astronomical Society of the Pacific for the Klumpke–Roberts Lecture Fund, named in honor of her parents and her husband. This has subsequently become the Klumpke–Roberts Award for those who have excelled in the popularization of astronomy.

Katherine Bracher

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Kneller, Andreas

Flourished **(the Netherlands), *circa* 1660**

Other than the fact that he lived in the Netherlands, little is known about Andreas Cellarius. His *Harmonica Macrocosmica*, one of the most beautiful celestial atlases of all time, is a snapshot of 17th-century cosmology: All three major systems (Ptolemaic, Tychonic, and Copernican) are lavishly illustrated by Cellarius.

Alternate name

Cellarius

Selected Reference

Friedman, Anna Felicity (1997). *Awestruck by the Majesty of the Heavens*. Chicago: Adler Planetarium and Astronomy Museum.

Knobel, Edward Ball

Born **London, England, 21 October 1841**
Died **probably London, England, 25 July 1930**

After **Christian H. Peters**' death, his editing and republication of **Ptolemy**'s *Almagest* was taken up by English amateur astronomer Edward Knobel. Knobel made significant observations of Mars and Jupiter, and was a cataloger of double stars.

Knobel was instrumental in resolving a major crisis in the Royal Astronomical Society [RAS]. His report on the Sadler–Smyth controversy – see **William Smyth** – was responsible for clearing Smyth's name and for Herbert Sadler's resignation from the RAS Council in disgrace.

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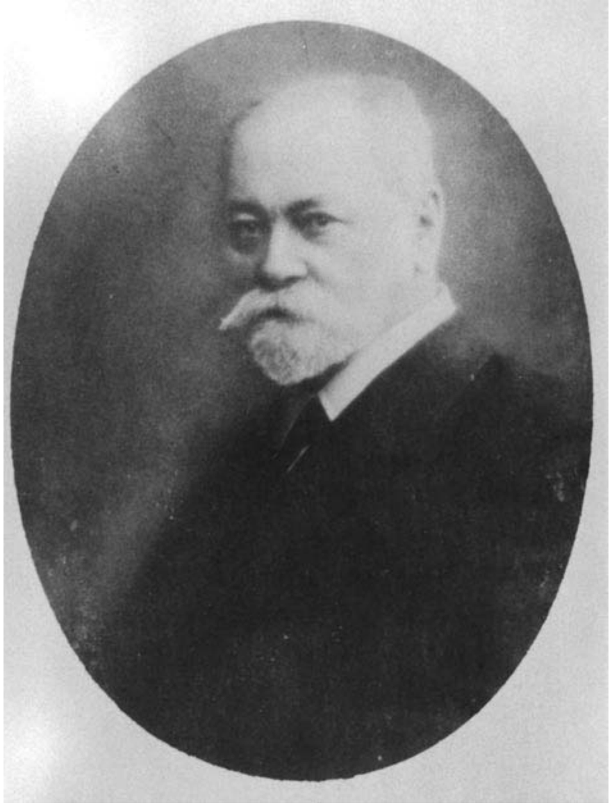
Knorre, Viktor Carl

Born **Nikolajew, (Ukraine), 4 October 1840**
Died **Lichterfelde, (Sachsen-Anhalt), Germany, 25 August 1919**



Viktor Knorre discovered four asteroids and contributed to telescope accessory and mounting improvements. A third-generation astronomer, Knorre was one of the 15 children of Karl Friedrich Knorre (1801–1883), director of the astronomical observatory in Crimea until 1871. Because of the difficult educational situation in Russia, Karl Knorre sent Viktor to school in Fellin, Estonia.

Knorre returned home after he had finished school and helped his father at the observatory for 2 years. In 1862 he left for Berlin, to study astronomy with Wilhelm Förster (1832–1921). After presenting his doctoral thesis Knorre went to Pulkovo Observatory in 1867 as an astronomical calculator. During his time there he traveled with Heinrich Wild (1833–1902) to inspect some meteorological stations and made observations to get the exact location of these stations. He also made magnetic observations.

In 1869 Knorre returned to Nikolajew where he first taught his younger brothers and sisters and then got a post as teacher at the local school. It seems that he earned a lot of praise but received little or no money at all for his work; he left for Berlin again to meet his father who had gone there after retiring from his post in Nikolajew. Knorre soon joined the Berlin Observatory as an observer, where he used the refractor made by **Joseph von Fraunhofer**. His main work involved minor planets, comets, and binary stars. On 4 January 1876 he discovered the minor planet (158) Koronis, followed by (215) Oenone, (238) Hypatia, and (271) Penthesilea in later years. For the observations of minor planets Knorre constructed a micrometer that he described in its various stages of development within the pages of the *Astronomische Nachrichten*.

Knorre also worked on the improvement of other instruments and equatorial telescope mountings. He did not take a post in teaching students at the University in Berlin but was always helpful in introducing new users to the telescopes.

In 1892 Knorre was appointed professor. In 1906 he retired and moved to Lichterfelde, close to Berlin, where he owned a house. Knorre found recreation, away from his ongoing scientific work, while working in the garden or playing chess. In 1909 and 1911 he published works on a new equatorial telescope mounting. A prototype was made by Heele at Knorre's expense.

Knorre died after a short illness.

Christof A. Plicht

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Poggendorff, J. C. "Knorre." In *Biographisch-literarisches Handwörterbuch*. Vol. 3 (1898): 731; Vol. 5 (1926): 646. Leipzig.

Kobold, Hermann Albert

Born **Hanover, (Germany), 5 August 1858**
Died **probably Kiel, Germany, 11 June 1942**

Hermann Kobol's more than 200 papers on comets, planets, asteroids, solar motion, eclipses, and the rotation of stellar systems appeared in several journals, including the *Astronomische Nachrichten*, which he edited between 1907 and 1938.

Kobold earned his Ph.D. from Göttingen in 1880; he was a pupil of **Ernst Klinkerfues.** Kobold was first employed as an assistant to **Miklós Konkoly Thege** at O'Gyalla Observatory in Hungary, and then at the University of Strasbourg. He was part of the German team for the 19th-century transits of Venus. In 1902, Kobold got a transfer to Kiel, where he became an "observator" and professor of astronomy at the university. Kobold also wrote a 1906 textbook on stellar astronomy. He retired in 1925.

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Poggendorff, J. C. (1926). "Kobold." In *Biographisch-literarisches Handwörterbuch*. Vol. 5, pp. 647–648. Leipzig: J. A. Barth.

Köhler, Johann Gottfried

Born **Gauernitz near Meissen, (Sachsen, Germany, 15 December 1745**
Died **Dresden, (Germany), 19 September 1801**

From 1776, Johann Köhler served as *Inspektor* (curator), and from about 1785 until his death as *Oberinspektor* (director), of both the Kunstkammer and the Mathematisch–Physikalischer Salon in Dresden. He published a list of "nebulae" in 1780. The list included several independent discoveries of deep-sky objects that eventually received numbers in **Charles Messier**'s catalog. Köhler's instruments also were apparently used by **Alexander von Humboldt** on his first voyage to South America.

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Kohlschütter, Arnold

Born **Halle, Germany, 6 July 1883**
Died **Bonn, (Germany), 28 May 1969**

Arnold Kohlschütter and **Walter Adams** found subtle criteria that could distinguish ordinary giants from dwarf stars.

Kohlschütter was educated at Göttingen University, a student of **Karl Schwarzschild**. He spent 3 years at Mount Wilson Observatory, California, from 1911 to 1914. There he cooperated with Adams in the work that led to a new method for determining the distances to stars.

Kohlschütter and Adams examined the spectra of stars with both large and small parallaxes, but similar apparent magnitudes. The stars with smaller parallaxes were necessarily more luminous. The two Mount Wilson spectroscopists found differences in the absorption-line strength ratios between the two sets of stars – even within the same spectral class. Once calibrated using stars of known distance, these differences could be observed in stars without measured parallax in order to determine their distances. The method refined the technique known as spectroscopic parallax. When coupled with the apparent magnitudes of the stars involved, this method allowed the determination of stellar distances greater than the limit measurable by trigonometric parallax, surpassing the quality of traditional parallax measurements at 25 pc.

In 1897, **Antonia Maury** had identified a few peculiar spectrograms characterized by some of the absorption lines being unusually sharp and others unusually strong for the stellar colors. **Ejnar Hertzprung** recognized in 1905 that these stars were supergiants, the brightest sort known. Kohlschütter and Adams found that differences in line properties arise from the lower gas densities in giant atmospheres, which sharpen those lines whose width is due mostly to Stark effect broadening and strengthen lines produced by ionized atoms, because recombination proceeds more slowly at low density.

In a second Mount Wilson collaboration, Kohlschütter and **Harlow Shapley** concluded that even strong absorption lines typically have a residual flux at their centers that is 20–30% of the continuum, meaning that the region of a stellar atmosphere responsible for the absorption features must be located near an optical depth of 0.2.

In 1918 Kohlschütter was appointed to the staff of Potsdam Observatory, and in 1925 became professor of astronomy at Bonn and director of the observatory there. He undertook the Bonn portion of the *Zweiter Katalog der Astronomischen Gesellschaft*, completed in 1958.

Kohlschütter was coauthor of the *Handbuch der Astrophysik* (1928; with Gustav Eberhard and **Hans Ludendorff**) and of a revised version of **Simon Newcomb**'s *Popular Astronomy* (1926).

Virginia Trimble and *Thomas Hockey*

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Schmidt, H. (1970). "Arnold Kohlschütter." *Astronomische Nachrichten*. 192: 142.

Kolhörster, Werner Heinrich Julius Gustav

Born **Schwiebus (Świebodzin, Poland), 28 December 1887**
Died **Munich, Germany, 5 August 1946**

Werner Kolhörster helped bring modern, quantitative methods to the study of cosmic rays.

Kolhörster earned his Ph.D. in physics under the direction of Friedrich Ernst Dorn at the University of Halle in 1911. He then became interested in the discovery of cosmic rays in the Earth's upper atmosphere by Austrian physicist **Victor Hess**, achieved by means of balloon ascensions (up to 5-km altitude) with an electrometer. Kolhörster extended the balloon-borne measurements up to 10-km altitude and fully demonstrated the validity of Hess's conclusions. He remained an assistant at the Physical Institute in Halle until the outbreak of World War I.

After the war, Kolhörster was forced into secondary teaching to support himself, at the Friedrich Werdersche Oberrealschule (*circa* 1920–1924) and the Sophien Realgymnasium, Berlin (*circa* 1924–1928). Nonetheless, Kolhörster became a guest investigator at the Physikalische-Technische Reichsanstalt in Berlin, where he significantly improved the instrumentation used to measure various types of radiation. He frequently tested his equipment in the Alps. In collaboration with physicist Walther Bothe, Kolhörster developed the so called coincidence method of scintillation counting, for which he was awarded the Leibniz Medal of the Prussian Academy of Sciences. Their joint papers in 1928 and 1929 were important in establishing that cosmic rays are very high energy particles, and not very short wavelength photons.

In 1928, Kolhörster was hired as an observer at the Magnetic-Meteorological Observatory at Potsdam. Two years later, he was appointed a *Privatdozent* (lecturer) in geophysics at the University of

Berlin, and concurrently designed the Dahlemer University Institute for High-altitude Radiation Research, the first such facility ever to be established. In 1935, Kolhörster became the laboratory's director and professor of radiation physics. He shared in the discovery of airshowers associated with the production of secondary cosmic rays.

With Leo Tuwim, Kolhörster wrote a leading text, *Physakalische Probleme der Höhenstrahlung* (Physical problems of high-altitude radiation).

Jordan D. Marché, II

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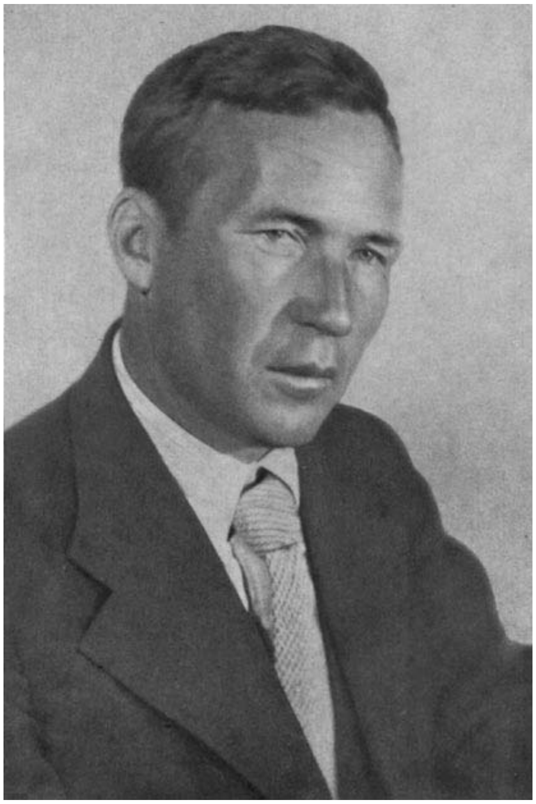
Kolmogorov, Andrei Nikolaevich

Born **Tambov, Russia, 25 April 1903**
Died **Moscow, (Russia), 20 October 1987**



The works of leading Soviet mathematician Andrei Kolmogorov found diverse applications in the treatment of dynamical systems and the study of turbulence or chaos theory as those fields applied to astronomy. The so called Kolmogorov spectrum describes, for instance, the structure of turbulence in the intersteller medium reasonably well. Kolmogorov's father was Nicholas Matveyevich Katayev; his mother, Maria Yakovlevna Katayeva (*née* Kolmogorova), died from complications surrounding his birth. He was then adopted by his aunt, Vera Yakovlevna Kolmogorova, and received her family name. He married Anna Dmitriyevna Kolmogorova (*née* Egorova).

Before the October 1917 Bolshevik Revolution, Kolmogorov studied in Moscow at the private E. A. Repmann Gymnasium; after the revolution, he attended a high school of the second level. In 1920, he was admitted to Moscow University as a student of the Faculty of Mathematics. There, Kolmogorov began his scientific activities under the guidance of professors P. S. Urysohn, A. K. Vlasov, V. V. Stepanov, and especially N. N. Luzin. In 1922, he acquired experience as a secondary school mathematics teacher, an occupation to which he voluntarily returned after the age of 60. Kolmogorov graduated from Moscow University in 1925 and then enlisted as a postgraduate student. After finishing postgraduate studies, Kolmogorov obtained a position as chair of mathematics at the Moscow Karl-Liebknecht Pedagogical Institute. He also began scientific research at the Mathematical Institute of Moscow University.

Kolmogorov's early research explored the theory of functions of a real variable. He investigated the convergence of trigonometric series, the theory of measure, the theory of functional approximations, set theory, and the theory of integrals. In 1925, working with A. J. Khintchine, he applied methods of the theory of functions to the theory of probabilities. In 1933, Kolmogorov constructed the axiomatic foundations of the theory of probabilities and established the theory of Markovian random processes in continuous time. During the period from 1939 to 1941, he solved extrapolation and interpolation problems concerning stationary processes. He clarified the link between the theories of random processes and that of Hilbert spaces and formulated many problems in terms of functional analysis. Kolmogorov investigated ergodic theorems and formulated the necessary and sufficient conditions of applicability for the law of large numbers. He made significant contributions to constructive logic and topology, having introduced in 1935 the so called upper limit operator (or Nabla-operator) and the topologic invariant of the cohomology ring. Kolmogorov formulated the idea of a topological vector space, and was deeply engaged in the theory of differential equations and in functional analysis. In his works concerning fluid mechanics, Kolmogorov created and developed the concept of local isotropy of turbulence in a viscous, incompressible fluid (at large Reynolds numbers), having established with Alexander M. Obukhov the spectrum of local turbulence (the Kolmogorov–Obukhov law of 2/3).

In celestial mechanics, Kolmogorov's results are especially applicable to the theory of dynamical systems as related to perturbed motions in Hamiltonian systems. These relationships describe, for example, the motion of an asteroid in an elliptical orbit under the perturbing influence of Jupiter. The same equations are pertinent to a wide range of problems addressing the stability of magnetic surfaces in fields with Tokamak geometries (*e. g.*, inside toroidal chambers known as "magnetic traps" and used in thermonuclear fusions experiments) and the stability of rapid rotation of a massive asymmetric rigid body. This work has been continued and expanded by his pupil, Vladimir I. Arnold, who examined the stability of quasi-periodicity in the three-body problem. Generalized methods to construct inverse functions by successive approximations, which overcame difficulties caused by small divisors, were developed by Kolmogorov, Arnold, and Jürgen Moser. The corresponding theory, known as KAM theory, draws its name from the initials of these three men. It plays an important role in investigations of the stability of the Solar System over very long (cosmogonical) timescales.

Kolmogorov was elected a member (academician) of the USSR Academy of Sciences (1939), the academician-secretary of the Department of Mathematics of the USSR Academy of Sciences (1939), a member of the USSR Academy of Pedagogical Sciences (1968), and president of the Moscow Mathematical Society (1964–1966). He received honorary doctoral degrees from the Paris Sorbonne University (1955), Stockholm University (1960), and the Institute of Statistics in India (1962). Kolmogorov was awarded the Stalin Prize (1940), the Eugenio Balzan Prize (1963), and the Lenin Prize (1965). He was declared a "Hero of the Socialist Labor" (1963) and was decorated with many orders and medals from the USSR, Hungary, and the German Democratic Republic.

Victor K. Abalakin

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Konkoly Thege, Miklós [Nikolaus]

Born **Pest (Budapest, Hungary), 20 January 1842**
Died **Budapest, (Hungary), 16 February 1916**

Well respected as an early participant in the evolution of astrophysics, Miklós Konkoly Thege founded an institute for the study of astronomy and astrophysics in Hungary using his own resources. He is rightly thought of as the founder of astronomy in Hungary, although such noteworthy astronomers as **János von Zach** and **Miska Höll** were Hungarian natives practicing astronomy abroad.

The Konkoly Thege family was Hungarian nobility with a considerable landed estate. His parents were Elek and Klára (*née* Földvári) Konkoly Thege. Miklós studied at the universities of Pest (1857–1860) and Berlin (1860–1862), earning a doctor of law degree. While in Berlin, he studied astronomy with **Johann Encke**, J. H. Dove, and H. G. Magnus.

Upon request of his parents he became the subprefect of a Hungarian county for a short time, but Konkoly Thege was much more interested in physics and astronomy. Skillful with his hands, he made his own instruments when becoming an astronomer. In his youth, Konkoly Thege traveled extensively, studied the European observatories, visited the leading optical and precision-mechanical workshops, and made acquaintance with distinguished astronomers of the period.

In 1871, Konkoly Thege built a private observatory on his own estate in Ógyalla (now Hurbanovo, Slovakia). He equipped the observatory with both purchased equipment and instruments he made in his own shops. The largest telescope was a 10.25-in. Browning silver-on-glass Newtonian reflector purchased in England (1874). The most important self-made instruments include a 10-in. refractor (still in use in the Debrecen Heliophysical Observatory), a 6.25-in. astrograph, a 5.25-in. telescope for solar photography, numerous spectrographs, and spectroscopes for observing prominences, meteors, comets, and other celestial objects.

Konkoly Thege's astronomical activity included extensive observational work on various celestial bodies, instrument development, and publication of handbooks on observational astronomy. During his study of sunspots Konkoly Thege drew the projected solar disk and determined the position and shape of the spots. From 1908 on, the sunspots were followed photographically. Sunspot results were reported regularly to Zürich.

Konkoly Thege was one of the first astronomers who carried out spectroscopic observations of meteors, attempting to determine their chemical composition. He studied the spectra of about 30 comets, a pursuit that earned him wide recognition.

At the request of **Hermann Vogel**, Konkoly Thege compiled a catalog describing the spectra of 2,022 stars observed from Ógyalla. Unfortunately, the stellar spectra in this catalog were classified according to the Potsdam Observatory system. Within a few years, after the publication of the Ógyalla catalog, the Harvard system of spectral classification was adopted internationally; in consequence the Ógyalla catalog is less well remembered today.

Konkoly Thege also made drawings of the surface features of the planets Mars and Jupiter. Konkoly Thege's published astronomical and astrophysical work is extensively cited in the contemporary literature, for example, in *A Treatise on Astronomical Spectroscopy*, **Edwin Frost**'s translation, and revision of **Julius Scheiner**'s earlier work.

Konkoly Thege's involvement in the invention and development of instrumentation for astronomy was significant and productive. Two of his inventions that deserve special mention in this regard were several types of a simple, direct vision solar flare telescope, and the blink comparator. One model of the solar flare spectroscope was marketed by Zeiss, though without acknowledging Konkoly Thege's role as the inventor. His blink comparator was eventually manufactured and marketed by G. Heide of Dresden.

One of Konkoly Thege's more lasting contributions to the development of astrophysics was in his publications of detailed instructions on technique. His several books on astrophysics were richly detailed and extensively illustrated with woodcut drawings of equipment. As a result, Konkoly Thege was asked to write the chapter on astrophotography for the influential four-volume compendium, *Handwörterbuch der Astronomie* edited by Karl Wilhelm Friedrich Johannes Valentiner (1845–1913).

As a mentor to other individuals interested in astronomy and astrophysics, Konkoly Thege performed the invaluable role of encouraging the development of other private observatories in Hungary. In addition to the well-equipped and productive observatory of **Jenõ von Gothard** at Herény, and Bishop Haynald's observatory in Kalocsa, Konkoly Thege was also instrumental in the founding of the Kiskartal Observatory of Baron Géza Podmaniczky. The Kiskartal Observatory employed several rising young professional astronomers, and was the site at which the Baroness Berta Dégenfeld-Schomburg made her independent discovery of the extragalactic supernova S Andromedae (SN 1885A). In addition to the scientific contributions of these private observatories, they enriched Hungarian astronomy with extensive collections of instruments and valuable libraries that form the basis for modern institutes in Hungary.

In 1890, Konkoly Thege was appointed director of the National Institute of Meteorology and Geomagnetism. During his directorship the forecast service was created, and the first meteorological maps appeared. The tasks of organization took up his days, leaving little time for astrophysics. Konkoly Thege suggested several times that he wished to transfer ownership of the Ógyalla Observatory to the state, but the problem was complicated by both the political instability and the financial weakness of the Habsburg Austro–Hungarian Empire. Konkoly Thege's highly creative solution to this problem was to invite the Astronomische Gesellschaft [AG] to hold its 17th assembly in Budapest in 1898. He was extremely well known and well-liked by European colleagues like **Willliam Huggins**, many of whom had visited his observatory. As a result the AG ignored a parallel invitation from the Heidelberg Observatory and elected to meet in Budapest. The pressure on Emperor Franz Josef and his cabinet from the resulting international gathering succeeded where other attempts had failed. The emperor himself made the announcement that the state would acquire the Ógyalla Observatory in his address to the assembled astronomers. Therefore in 1899, Konkoly Thege donated the Ógyalla Observatory to the Hungarian state. The observatory's successor is now the Konkoly Observatory of the Hungarian Academy of Sciences, with its headquarters in Budapest.

Konkoly Thege was elected corresponding member (1876), then honorary member (1885) of the Hungarian Academy of Sciences, and a member of the Astronomische Gesellschaft and the Royal Astronomical Society. The minor planet (1445) Konkolya is named for him.

Konkoly Thege retired from his position at the Meteorological Institute in 1911. He was also a talented pianist and qualified maritime engineer and ship captain. In his later years he was again involved in politics as a member of the Hungarian parliament (from 1896 to 1906). Konkoly Thege married Erzsébet Madarassy; their two children died in early childhood.

László Szabados

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Kopal, Zdeněk

Born **Litomysl, (Czech Republic), 4 April 1914**
Died **Manchester, England, 23 June 1993**

Czech–American–English astronomer Zdeněk Kopal is most often associated with studies of close binaries and their implications for the interior physics of stars and kinds of systems observed. A youthful enthusiastic amateur astronomer, Kopal joined the Czech Astronomical Society in 1929 and became chair of its section on variable stars in 1931. He received a Ph.D. *summa cum laude* in physics and mathematics at the Charles University of Prague (by then part of Czechoslovakia) in 1937, studied under **Arthur Eddington** in Cambridge, England, in 1938, and took an appointment at **Harlow Shapley**'s Harvard College Observatory at the end of that year. Kopal quickly became an American citizen and worked on ballistics for the United States Navy at the Massachusetts Institute of Technology during World War II, as well as contributing to the mathematics needed for the first generation of computers. In 1951 he became professor and founding chair of the Astronomy Department at the University of Manchester, retiring in 1981 but remaining an active professor emeritus for the rest of his life. His daughter Zdenka married a British astronomer.

Kopal's Ph.D. dissertation already focused on the development of numerical methods for study of close pairs of stars, for instance decomposition of the light curve into Fourier components, and he continued this work in Cambridge, England, and Cambridge, Massachusetts, USA. An early result was that the density distribution of stars must be far more centrally condensed than modelers had supposed for the rotation of the line of apsides of binary orbits to be as slow as it is. **Thomas Cowling** was able to show with **Ludwig Biermann** that Kopal had made a serious error in neglecting the tidal distortion of the shapes of stars, which puts them very nearly into equilibrium, so that they drag on each other very little. With this correction, apsidal motion and other probes of stellar interiors gave concordant results. At Manchester, Kopal produced his classic text, *Close Binary Systems* (1959), in which he summarized the state of the subject just before a three-pronged assault on binary evolution with transfer of material between the stars began in Europe. It is no coincidence that one of the three groups, under Miroslav Plavec, was working at his own Charles University, and Kopal maintained close contact with the Czech astronomical community thereafter.

The concept of mass transfer in binaries can be traced back to **Gerard Kuiper** in 1935, and Kopal 20 years later drew the critical distinction among detached systems (both stars smaller than their Roche lobes), semidetached systems (one star filling its lobe and transferring material to the other), and contact systems, where both stars fill their lobes and material can move back and forth.

With the advent of the space age, Kopal became fascinated by the idea of landing people on the Moon. Realizing that very good Moon maps would be needed, he obtained sponsorship from the United States Air Force to obtain a large number of very high resolution images from the high-altitude observatory at Pic du Midi in the French Pyrenees. The funding was lavish by British standards of the time and enabled Kopal to bring students to Manchester from all over the Middle East. Many of them returned to their home countries to begin astronomy programs there, and the legacy can still be discerned in the relatively large number of papers from these countries published in one of the journals Kopal founded.

By 1962, Kopal recognized that the assortment of journals then being published did not really provide an adequate home for the rapidly increasing literature on Solar System physics and astronomy. He therefore became the founding editor of *Icarus*, published by Academic Press, but turned the editorship over to others (initially Carl Sagan) in 1969. His second foray into publishing came with the recognition that there was also no journal focusing on results obtained from space by scientists in all the countries that hoped to pursue space programs. Thus came into being *Astrophysics and Space Science*, a Reidel journal for which Kopal remained an editor until his death, when it was taken over by his younger colleague at Manchester, John Dyson. Kopal usually maintained a friendly relationship with his authors, sometimes handwriting letters of acceptance. He remained active in space-based research throughout the remainder of his career, writing shortly before his death, for instance, on the shape of the nucleus of comet 1P/Halley as revealed in photographs by the Giotto mission.

Kopal served as an officer of the Royal Astronomical Society and commissions of the International Astronomical Union. He was elected a honorary member of the Czech Astronomical Society in 1967, and minor planet (2628) is named Kopal. Kopal was the author of several popular books as well as many technical publications.

Jiří Grygar

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Meaburn, John (1994). "Zdenek Kopal (1914–1993)." *Quarterly Journal of the Royal Astronomical Society* 35: 229–230.

Kopff, August

Born **Heidelberg, Germany, 5 February 1882**
Died **Heidelberg, (Germany), 25 April 1960**

Comet and Trojan asteroid discoverer August Kopff was the son of a master plumber in Heidelberg. From 1900 to 1905 he studied mathematics, physics, and astronomy at the University of Heidelberg, where he got his Ph.D. in 1906 with a paper on "Über die Nebel der Nova Persei." Among his academic teachers were astronomer **Maximilian Wolf**, who founded the Königstuhl Observatory at the University of Heidelberg, mathematician Leo Königsberger (1837–1921), and physicist Georg Quincke (1834–1924). By 1901, Kopff began work with Wolf at the observatory. In 1907 Kopff became *Privatdozent* (lecturer), and in 1912 a professor at the University of Heidelberg. After military service during World War I, Kopff returned to teaching and observing at the University of Heidelberg. In 1924, Kopff became professor of theoretical astronomy at the University of Berlin and simultaneously – as a successor of Fritz Cohn (1866–1921) – director of the Institute for Astronomical Calculation (*Astronomisches* Recheninstitut in Berlin-Dahlem, Germany). (During World War II this institute was evacuated to Saxony, and found a new accommodation in 1945 in Heidelberg.) From 1947 up to his retirement in 1950 Kopff was professor of astronomy at the University of Heidelberg, and besides his directorship of the institute (until 1954) also director of the observatory.

In his time at Königstuhl, Kopff took part in all observation programs of the observatory and published studies on the theory of comets, stellar astronomy, and the theory of relativity. During his time in Berlin he and his co-workers published several catalogs of stars. One of the main projects was the third fundamental catalog of the FK-series (1935), which was adopted as the standard list of fundamental stars by the International Astronomical Union [IAU].

Kopff had memberships to the Academy of Sciences at Berlin (1935), the Deutsche Akademie der Naturforscher Leopoldina (1936), and the American Astronomical Society (honorary, 1949), and was associate of the Royal Astronomical Society (London). He was also actively engaged in the organization of the Astronomische Gesellschaft, to whose council he belonged since 1930. A lunar crater is named for him.

Horst Kant

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Koppernigk, Nicolaus [Nicholas]

➜ **Copernicus [Coppernig, Copernik], Nicolaus [Nicholas]**

Kordylewski, Kazimierz

Born **Poznan, Poland, 11 October 1903**
Died **Cracow, Poland, 11 March 1981**

A versatile and prolific observer, Kazimierz Kordylewski discovered the "dust clouds" accompanying Lagrangian points L4 and L5 along the Earth's orbit. Son of Wladyslaw and Franciszka (*née* Woroch) Kordylewski, he first attended Poznan University (1922–1924), after which he became an assistant at the Cracow Observatory (1924–1934) and later an adjunct instructor. Kordylewski received his Ph.D. at Jagiellonian University in Cracow (1932). He married Jadwiga Pojak in 1929; the couple had four children.

An accomplished mathematician, Kordylewski calculated the orbits of many comets and minor planets, although his principal work involved the photoelectric photometry of variable stars and the cinematography of solar eclipses. He discovered the nova T Corvi in 1926. Between 1939 and 1951, Kordylewski directed the scientific instruments section of the National Astronomical Copernicus Institute, at Cracow, as well as the institute itself. After 1958, he was chief of the observing station for artificial satellites, and edited the *Eclipsing Binaries Circulars* (1960–). Kordylewski was president of the Cracow branch of the Polish Astronomical Society (1956–).

In 1951, Kordylewski began to hunt for small "Trojan" satellites of the Earth at the L4 and L5 libration points, located 60° ahead of and behind the Moon in its orbit. His initial visual search with a 30-cm refractor proved unsuccessful. Then in 1956, professor Josef Witkowski suggested that Kordylewski stop looking for solid bodies and search instead for faint luminous patches of dust. Following this advice, when observing from the Skalnaté Pleso Observatory in Czechoslovakia's Tatras Mountains in 1956, Kordylewski managed to glimpse with his naked eye an exceedingly faint, diffuse patch of light subtending an apparent angle of 2° at one of the Lagrangian points. He estimated its brightness as only half that of the notoriously difficult Gegenschein. In March and April of 1961, Kordylewski succeeded in capturing images of these transient clouds on film and subjected them to isodensitometry measurements.

Although they were observed as early as January 1964 by the American amateur astronomer John Wesley Simpson (1914–1977) and his colleagues in the Santa Cruz Mountains of California, the reality of the Kordylewski clouds was debated until 1975, when J. R. Roach announced their detection using data acquired over a 15-month period by the Orbiting Solar Observatory 6 [OSO-6] spacecraft. The clouds were subsequently photographed on many occasions by Maciej Winiarski, using batteries of wide-angle cameras at a dark site in Poland's Bieszczady Mountains. Thus, Kordylewski is remembered as the discoverer of these ephemeral natural satellites of the Earth, the culmination of a century-long hunt for a "second Moon."

Thomas A. Dobbins

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Korff, Serge Alexander

Born **Helsinki, (Finland), 1906**
Died **New York, New York, USA, 1 December 1989**

Russian–American nuclear and cosmic-ray experimental physicist Serge Korff is known primarily for inventing the class of particle detector called the wire proportional counter and applying it to a range of problems in physics and astronomy. This included the demonstration that cosmic-ray particles carry positive charge, and so must be mostly protons.

Of Russian–American parentage, Korff came to the United States after the October (1917) Revolution deprived his father of his job as lieutenant governor of Finland. Korff received degrees from Princeton (BA: 1928, MA: 1929, Ph.D.: 1931) and held fellowships at Mount Wilson Observatory, the California Institute of Technology, and the Bartol Research Foundation before joining the physics department of New York University in 1941. He retired as professor emeritus in 1973.

Korff participated in expeditions to high-altitude sites to study cosmic rays from 1934 (Mexico) to 1957 (Alaska). The 1934/1935 Peruvian expedition demonstrated beyond doubt the bending of cosmic-ray paths by the Earth's magnetic field and, therefore, the positive charge carried by the particles. His later work on cosmic rays was relevant to radiocarbon dating (*via* the variable production ratio of carbon-14 by cosmic-ray secondary neutrons in the upper atmosphere), radiation hazards of high-altitude flight, and our understanding of the effects of the solar wind on galactic cosmic rays reaching the Earth. Most of the later work was done from balloons and rockets rather than mountain sites, but Korff served for many years on committees devoted to high-altitude research as well as to USA–Latin American scientific cooperation.

Korff received honors from France, Cyprus, Greece, and the United Kingdom, as well as the United States, and was president of the American Geographical Society (1966–1971), the Explorers' Club (1955–1958 and 1961–1963), and the New York Academy of Sciences (1971–1972). His younger colleagues proudly referred to themselves as Korff's balloonatics.

Virginia Trimble

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Kovalsky, Marian Albertovich

Born **Dobrzin, Poland, 15/27 August 1821**
Died **Kazan, Russia, 28 May/9 June 1884**

Marian Kovalsky developed new methods in celestial mechanics, composed a zone catalog of northern stars, and studied the motions of stars in the Milky Way. Born into the Polish family of Albert Kovalsky, he matriculated at Saint Petersburg University in 1841 and studied astronomy under **Friedrich Struve** and Aleksei Nikolaevich Savich. Graduating in 1845, Kovalsky spent a year at the Pulkovo Observatory before earning his master's degree (1847) on the motions of comets. Over the next 2 years, he participated in geodetic expeditions conducted by the Russian Geographical Society. In 1849, Kovalsky was made an assistant, and in 1850, a lecturer on astronomy at Kazan University. His doctoral dissertation was awarded in 1852 for his theory of the orbit of Neptune. In that year, Kovalsky was appointed a full professor and in 1855 became director of the university's observatory. He married Henriette Serafimovna Gatsisskaya in 1856; the couple had one son.

Kovalsky's subsequent research elaborated upon the mathematical theory of solar eclipses; he also proposed a simplified method to calculate occultations of stars by the Moon. At the Kazan Observatory, he measured the positions and prepared the zone catalog (published in 1887 for the Astronomische Gesellschaft) of more than 4,200 stars whose declinations lay between 75° and 80°. Kovalsky's most important work, however, concerned his analysis (1860) of the proper motions of stars. Independently of Astronomer Royal **George Airy**, Kovalsky employed data from the star catalog of **James Bradley** to derive improved estimates of the Sun's own motion through space and identified a significant deviation in stellar motions that was not explained for several decades. His work refuted one theory of a "central sun" proposed in 1846 by astronomer **Johann von Mädler** and instead supported contemporary notions of our Galaxy's solid-body rotation.

Kovalsky was appointed a corresponding member of the Saint Petersburg Academy of Sciences (1863), a member of the Royal Astronomical Society (1863), and a founding member of the Astronomische Gesellschaft (1864).

Mihkel Joeveer

Alternate name

Voytekhovich, Marian Albertovich

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Anon. (1951). "Marian Albertovich Kovalsky." In *Vydaiushchiesia russkie astronomy* (Outstanding Russian astronomers), edited by Iu. G. Perel, pp. 108–122. Moscow: Gos. izd-vo techniko-teoreticheskoi literatury.

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Struve, Otto (1962). "M. A. Kovalsky and His Work on Stellar Motions." *Sky & Telescope* 23, no. 5: 250–252.

Kozyrev, Nikolai Alexandrovich

Born **Saint Petersburg, Russia, 2 September 1908**
Died **near Leningrad (Saint Petersburg, Russia), 27 February 1983**

Russian astrophysicist Nikolai Kozyrev is best remembered for his claim that he recorded photographically the spectra of emission from gas on the Moon no fewer than four times. This has been widely accepted as evidence that the Moon is not (quite) geologically dead.

Kozyrev graduated from the University of Leningrad in 1928 and, in 1931, was appointed to the staff at Pulkov Astronomical Observatory. He also worked at various times at the observatories in Kharkov, Ukraine, and in the Crimea. Kozyrev was part of the large group of Pulkovo Observatory astronomers (most famously **Boris Gerasimovich**) who were arrested in 1936 and imprisoned or executed. Kozyrev appears briefly in the memoir *The Gulag Archipelago* by Alexander Solzhenitsyn, because the author was deeply impressed by his efforts to continue to carry out work in astrophysics under extraordinarily hostile circumstances. Released in January 1947, Kozyrev set to work to rebuild his shattered career. Despite the unconventionality of his post-World War II work, Kozyrev maintained a formal affiliation with the main astronomical observatory (Pulkovo) of the Soviet Academy of Sciences until the official retirement age.

During the autumn of 1958 Kozyrev began to examine the crater Alphonosus with the Crimean Astrophysical Observatory's 1.3-m Zeiss reflector, which was equipped with a prism spectrograph. On the night of 3 November 1958, when the phase of the Moon was 1 day before last quarter, Kozyrev placed the slit of the spectrograph across the central peak of Alphonsus and opened the shutter of the camera to begin a 30-min exposure. Keeping his eye glued to the eyepiece of a 6-in. auxiliary guidescope, he made frequent manual corrections to keep the slit of the spectrograph centered over the crater's central peak.

While guiding the exposure, Kozyrev noticed that the central peak "appeared brighter and whiter than usual," until "suddenly, in a period of less than a minute, the brightness of the peak dropped to normal." (It was late afternoon in Alphonsus at the time, so these impressions are hardly startling.) He stopped the exposure and inserted a second plate to record the spectrum of the peak, now "in its normal state." This second exposure lasted 10 min. On the first plate, Kozyrev claimed that he could make out a set of faint emission bands centered at 474 nm and 440 nm, but these features were absent on the comparison plate. He attributed them to ionized molecules of diatomic carbon in a rapidly expanding, rarefied cloud of gas released from the central peak and excited to fluorescence by solar ultraviolet radiation. Curiously, the chemical composition of the gas was not similar to terrestrial volcanic emissions, but seemed to resemble the materials found in the nuclei of comets.

Kozyrev's account appeared in the February 1959 issue of *Sky & Telescope*, complete with reproductions of his spectrograms. Expert spectroscopists who examined Kozyrev's images suspected that his "emission bands" were simply artifacts of faulty guiding. Guiding errors would be far less pronounced in the second comparison spectrum, which was exposed with the benefit of the half hour of practice spent guiding the first spectrum and for only one-third the length of time, convincingly accounting for its dearth of supposed emission bands.

At least initially, the report was widely believed and regarded as very significant. Kozyrev received a variety of kinds of recognition, including the statement from Dinsmore Alter that the spectrum was "the most important single lunar observation ever made."

One might expect that witnessing even the rather quiescent emission of gas from a lunar volcano would be a once-in-a-lifetime chance occurrence, so eyebrows were raised in 1960 when Kozyrev announced that he had managed to record a second event in Alphonsus, and this time nothing less than a *bona fide* volcanic eruption. This time there were no "peculiarities in the appearance of the crater," so no comparison spectrum was taken. Kozyrev detected a very slight "uniform increase in contrast" between 530 nm and 660 nm, attributing it to the thermal blackbody radiation emitted by a flow of lava.

This time reaction to Kozyrev's announcement was considerably less ethusiastic. Doubts were further compounded in 1963 when Kozyrev reported that he had repeatedly recorded the emission lines of excited molecular hydrogen in spectra of the crater Aristarchus. In 1969, he announced that new spectra of Aristarchus featured the lines of ionized molecular nitrogen and hydrogen cyanide, but by this time pronouncements elicited few comments.

With the Cold War at its height at this time, direct exchanges between western scientists and their Soviet counterparts were limited. During a visit to the United States, one of Kozyrev's colleagues, the astronomer V. I. Krassovsky, confided to his hosts that not only were Kozyrev's spectra "defective," but that Kozyrev himself was "personally unstable." Few could have imagined the ordeal that may have prompted this appraisal.

Doubts about Kozyrev's lunar spectra are certainly valid when they are considered in the context of some of his other spectrographic "discoveries." In 1954 Kozyrev announced that he had obtained spectrograms of a glow emanating from the night side of Venus. While the reality of the socalled ashen light continues to be debated to this day, even its proponents reacted with incredulity to Kozyrev's claim that the emission he recorded was 50 times brighter than terrestrial "airglow."

The following year Kozyrev published a bizarre claim that the characteristic ruddy color of Mars is an illusion caused by the optical properties of the planet's tenuous atmosphere, which he mistakenly alleged was all but opaque to wavelengths shorter than 500 nm. In 1966 Kozyrev announced the presence of absorption bands in spectra of Saturn's rings that suggested a tenuous atmosphere of ammonia; data from the Voyager space probes have ruled out such a possibility.

During a transit of Mercury in 1973, Kozyrev reported that he was able to detect the emission lines of hydrogen in an atmosphere about 1/100 as dense as the Earth's. The ultraviolet spectrograph aboard the Mariner 10 space probe did detect a hydrogen halo during its flyby of Mercury the following year, but it proved to be 10 trillion times more rarefied than the one postulated by Kozyrev, far beyond the threshold of his instrument.

Even more serious questions are raised by Kozyrev's forays into experimental physics. In 1951 he embarked on a prolonged series of experiments with gyroscopes, torsion balances, and pendulums in the laboratory of the Pulkovo Observatory, inspired by ruminations on the nature of time during his dreary years in captivity. Fifteen years later he published a number of utterly incredible claims: That he had observed quantum effects on a macroscopic scale, that time possesses a variable spatial density and can be shielded against by interposing chiral organic compounds, and that information can be propagated instantaneously through space – seemingly in violation of special relativity. His gyroscope experiments led Kozyrev to infer that the distance from the Equator to the north pole of a rapidly rotating planet should be less than the distance from Equator to its south pole, and he claimed to have confirmed this nonexistent asymmetry by measuring photographs of Jupiter and Saturn. His theory of "causal mechanics" held that the energy source of stars is not thermonuclear but derives from "the flow of time."

Kozyrev's lunar spectra continue to be cited as evidence that the Moon is not quite geologically dead, a tale that is often told in a distorted form and seldom with even a passing reference to the peculiarities of his other work. Yet some of Kozyrev's work is quite praiseworthy, notably his 1974 observations of the azimuthal brightness asymmetry in the rings of Saturn.

Thomas A. Dobbins and *William Sheehan*

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Krafft, Johann

➔ **John of Gmunden**

Krebs, Nicholas

Born **Cusa, (Rheinland-Pfalz, Germany), 1401**
Died **(Germany), 1464**

Nicholas Krebs is generally regarded as a key transitional figure between the Middle Ages and the Renaissance. He gave the study of the Universe a legitimacy that would be exploited by the cosmologists of the 17th and 18th centuries.

Krebs's father was a boatman on the Moselle River. In 1413 he joined the Brothers of the Common Life at Deventer in the Lowlands, a group of mystics devoted to experiencing unity with God as inspired by a widely influential book of the time, *Imitatio Christi* (Imitation of Christ). Krebs went on to study philosophy, law, mathematics, the sciences, theology, and the arts at the universities of Heidelberg, Rome, Cologne, and Padua, where he received his doctorate in law. After he was ordained in 1433, he pursued a series of ecclesiastical appointments, culminating in his becoming cardinal in 1448 and Bishop of Brixen in 1450.

Krebs's most important philosophical innovation – the concept of the identity of opposites (*coincidentia oppositorun*), developed in his major philosophical work, *De Docta Ignorantia* (Of learned ignorance, 1440)—is the idea that the distinctions and oppositions among finite beings resolve into unity at the absolute level. His arguments are remarkable for their analytical sophistication. Draw, for instance, a series of bigger and bigger circles, all of which touch a straight line at a point. As the circles get bigger, the more the curve "flattens out" and approaches the straightness of the line, so that if you could thus draw an *infinitely large* circle and place it against the line, there would no longer be any difference between the "curved" line of the circle and the straight line. In this precise way Krebs argues that in the infinite all the opposites become one; thus his oft-misunderstood "mystical" thesis that "everything is everything."

Inspired both by Neoplatonic philosophy and 13th-century mysticism, Krebs's thought developed in marked opposition to scholastic Aristotelianism. Striving for a synthesis of, on the one hand, mathematical and experimental knowledge and, on the other, mysticism and knowledge, Krebs made brilliant and original use of analogies from mathematics. He built a system of epistemology and metaphysics in which the categories of reason, with their opposites and contradictions, give us at best only a limited and inadequate representation of reality that in itself is beyond our direct access and understanding. Krebs's work thereby anticipated the great system of **Immanuel Kant**. Reason is by its very nature discursive, and because our thinking is discursive any conclusions drawn upon it are attained through a series of inferences and not by direct insight. Although it is possible for the intellect to transcend these limitations through intuitive cognitions apprehended all at once, our language cannot adequately express these intuitions because it relies necessarily on categories, oppositions, and contradictions that exist only at the finite, relative level of immediate experience. The unity of opposites in ultimate reality can therefore never be directly or fully attained by us; however, once the mind sees that this cannot be attained, it is then capable of transcending the very linguistic and conceptual limitations once it understands their necessity.

Another fascinating upshot of Krebs' line of thinking is that in studying the Universe we are studying God. This is an idea that reverberated throughout the Renaissance, especially as brought to fruition by scientists like **Galileo Galilei**, who sought to study nature directly rather than through official scriptures to learn about God and the origin of the Universe. The Universe according to Krebs is a theophany, an "appearance of God." In anticipation of the cosmology of **Giordano Bruno** and Baruch Spinoza, Krebs viewed the Universe as endless unfoldings of God; the present "expansion" of existence is, according to his theory, the result of a divine "contraction" from which the unity of God unfolds into multiplicity, an anticipation of 20th-century cyclical cosmological theory. The Universe is therefore itself infinite, which led Krebs to reject the idea of fixed points in space and time in a way that further anticipated 20th-century developments in the relativity of space and time as pioneered by **Albert Einstein**. No place in the Universe – neither on the Earth nor on the Sun – is a privileged position. All judgments about location must therefore be relative. Krebs then even went on to conclude that the geocentric view of the Solar System expressed by the Old Testament is false.

According to Krebs, each individual entity in the Universe is a manifestation of the whole, forming a harmonious system in which each is both unique and part of the whole. His revival of the key phrase from **Anaxagoras**, "everything is in everything," states that everything mirrors the entire Universe, just as conceived in **Gottfried Leibniz's** subsequent theory of monads. The whole of being is in everything, and everything is in the whole. And anticipating both Spinoza and Leibniz still further, he concluded: "all things are what they are, because they could not be otherwise nor better."

The ultimate goal of all inquiry, described in Kreb's final work, *De Visione Dei* (Vision of God, 1453), is the transcendence of the limitations of sensory knowledge to attain through intellectual intuition a vision that goes beyond reason, logic, and language, thereby returning the finite to the infinite and allowing us to achieve a mystical union with the Universe. We are then free to live out the rest of our lives in mystical contemplation of the oneness of all things, a transcendental bridge between the relative, finite world and the absolute, infinite Universe.

Daniel Kolak

Alternate names

Nicholas Cusanus
Nikolaus von Cusa
Nicholas of Cusa

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Yamaki, Kazuhiko (ed.) (2002). *Nicholas of Cusa: A Medieval Thinker for the Modern Age*. Richmond, Surrey: Curzon Press.

Kremer, Gerhard

Born **Rupelmonde, Flanders (Belgium), 1512**
Died **Duisburg, Nordrhein-Westfalen, Germany, 1594**

Cartographer Gerardus Mercator's map projection is still in use today and has also proved useful for uranography.

Mercator was born in a German family. He studied geography, cartography, and mathematics at the University of Louvain in what is now Belgium, graduating in 1532. He published his first map (of Palestine) in 1537 at the age of 25. From 1537 to 1540 he surveyed and mapped Flanders, and in 1538 he made and published his first world map, based on the **Ptolemy** map. In 1554 Mercator produced a map of Europe. He did cartographical work for Emperor Charles V and was cosmographer to the Duke of Jülich and Cleves. In 1544, he was arrested and prosecuted for heresy, and in 1552 he moved to Duisburg to evade religious persecution because he was a Protestant.

Mercator solved the problem of depicting a spherical surface on a flat piece of paper in 1568, by using the "cylindrical projection." He used a new way of displaying a map with parallel lines for the latitudes and meridians at 90° to each other. The Mercator projection, using straight lines to indicate latitude and longitude, was a great progress for navigation at sea. Its disadvantage is the disproportion of size: Greenland, for instance, is shown 16 times larger than it is in reality.

Mercator's main work, a three-volume world atlas, was published in several editions from 1585 on, and after his death, by his son. He was the first to use the word "atlas."

Fathi Habashi

Alternate name

Gerardus Mercator

Selected Reference

Debus, Allen G. (ed.) (1968). "Mercator, Gerhardus." In *World Who's Who in Science*, p. 1162. Chicago: Marquis Who's Who.

Kreutz, Heinrich Carl Friedrich

Born **Siegen (Nordrhein-Westfalen, Germany), 28 September 1854**
Died **Kiel, Germany, 13 July 1907**

Heinrich Kreutz is chiefly remembered for his work on sun-grazing comets and his editorship of the *Astronomische Nachrichten* (1896–1907). He was the son of a superintendent of Siegen. After obtaining his secondary education in Siegen, Kreutz studied astronomy at the University of Bonn under the tutorship of **Eduard Schönfeld** and **Carl Krüger**. He was awarded his Ph.D. in 1880 for a study of the orbit of the great comet C/1861 J1. Afterward, Kreutz spent several months in Vienna with **Edmund Weiss** and **Theodor von Oppolzer**. For roughly a year, he served as a computer at the Recheninstitut in Berlin.

In 1883, Kreutz's former professor, Krüger, was appointed director of the Kiel Observatory. Along with this responsibility, Krüger assumed the editorship of the *Astronomische Nachrichten*, then the world's leading astronomical journal. Kreutz followed Krüger to Kiel, where he accepted a position as computer. From the beginning, however, Kreutz was involved in the editorial work of the *Astronomische Nachrichten*. In 1888, he was also appointed as lecturer at the University of Kiel; by 1891, he was named an associate professor. About that time, Kreutz married Krüger's daughter.

Upon Krüger's death in 1896, Kreutz succeeded him as editor of the *Astronomische Nachrichten*, a position he held for the rest of his life. In that capacity, he produced its volumes 140–175. Kreutz performed these duties with great care and maintained the journal's high standards for publication. When faced with an increasing number of longer papers, he founded the *Astronomische Abhandlungen* (1901), to provide a forum of more comprehensive accounts. Thirteen issues of the *Abhandlungen* were published before his death. Kreutz also directed the headquarters for astronomical telegrams.

Kreutz's most important astronomical research work was his investigation of the orbits of the great sun-grazing comets C/1843 D1, C/1880 C1, and C/1882 R1. Through extensive computational work, he provided evidence that these bodies were all members of a similar group of comets, now called the "Kreutz group," which had their origins in the breakup of a once-larger celestial body.

Hartmut Frommert

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Seeliger, Hugo von (1907). "Todes-Anzeige: Heinrich Kreutz." *Astronomische Nachrichten* 175: 241–244.

Krieger, Johann Nepomuk

Born **Unterwiesenbach, (Bavaria, Germany), 1865**
Died **Munich, Germany, February 1902**

Johann Krieger completed less than one-third of a planned lunar atlas that showed great promise before he died, his health ruined by his obsessive commitment to the mapping project. The son of a brewer, Krieger was little more than a boy when he started to observe the Moon with a small refractor from the sleepy mountain hamlet of Unterwiesenbach, where his scanty education ended at the age of 15. Six years later he traveled to Cologne to visit **Hermann Klein**, the foremost German selenographer and popularizer of astronomy of the era. Klein not only warmly encouraged Krieger to make selenography his life's work, but assumed the role of his mentor, directing the young man to study mathematics, physics, photography, and the graphic arts.

Krieger's ensuing academic career faltered because he lacked the mathematical aptitude required for the rigorous curriculum at the University of Munich. Undeterred, he spent his inheritance to establish a private observatory in the Munich suburb of Gern-Nymphenburg. Krieger equipped his observatory with a fine 270-mm refractor and announced his intention to produce an exhaustive lunar atlas. In the quest for a better astronomical climate, he would move his observatory to Trieste on the Adriatic coast several years later.

Klein provided Krieger with photographic prints made from the best lunar negatives taken at the Lick and Paris observatories. The photographs were enlarged to a scale of almost 12 ft. to the Moon's diameter. These grainy, low-contrast prints served as the substrates for Krieger's drawings, ensuring an exceptional level of positional accuracy and proper proportion. At the eyepiece Krieger used different colored pencils on successive nights to sketch the finest details glimpsed in fleeting moments of steady seeing that were far beyond the capability of photography to record. These sketches served as the basis for magnificent shaded drawings executed with India ink, graphite pencil, charcoal, and paper stumps that were almost universally recognized as startlingly superior in their meticulous accuracy, aesthetic appeal, and legibility.

The frantic, monomaniacal pace at which Krieger labored would quickly take its toll, and in only a few short years his health would utterly collapse. He died early, a martyr to selenography. He had completed less than a third of the plates for his atlas, and these would only be published, in rough and fragmentary form, 10 years after his death.

Krieger's work was collected and edited by his friend Rudolf König (1865–1927), an Austrian businessman who was a mathematician and amateur astronomer of rare ability. König published the two lavish volumes of *Johann Nepomuk Kriegers Mond-Atlas*, but only 18 of the 58 plates had been completed by Krieger, the remainder being little more than rough outlines.

Thomas A. Dobbins

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Kron, Gerald Edward

Born **Milwaukee, Wisconsin, USA, 6 April 1913**

American photometrist Gerald E. Kron developed a system for measuring colors of stars and other astronomical objects; his system is now called Kron–Cousins (sometimes Kron–Cousins–Johnson) colors. Kron received his BS (1933) and MS (1934) degrees from the University of Wisconsin, and a Ph.D. (1938) from the University of California (Berkeley) for a thesis on the design, construction, and use of a photoelectric photometer for the 36-in. refractor at the Lick Observatory. He joined the staff of the Lick Observatory as a junior astronomer in 1938 and remained there, apart from research associateships at the Massachusetts Institute of Technology and California Institute of Technology, and war work at the United States Naval Ordnance Test Station in California, rising through the ranks until 1965.

With **Joel Stebbins**, a pioneer of photoelectric photometry, Kron applied a new six-color system to variable stars and eclipsing binaries. Other early collaborators were **Joseph Moore** and **Arthur Wyse**.

In 1965, Kron was appointed director of the United States Naval Observatory [USNO] Station in Flagstaff, Arizona, where he developed an electronic camera for its astrometric reflector. He continued to work on photometry of variable stars and globular clusters, reconciling the properties of galaxies as reported in the Zwicky and Shapley–Ames catalogs, and clarifying the nature of the emission from the jets of active galaxies like M87 and the quasar 3C273. He also made major contributions to our understanding of the distribution of interstellar reddening.

Kron has been headquartered at the private Pinecrest Observatory most of the time since his 1973 retirement from USNO. His wife, Katherine C. Gordon (whom he married in 1946) and their son Richard G. Kron are also astronomers.

Steven J. Dick

Selected Reference

Kron, Gerald (1973). *A Catalog of Colorimetric Measures of Stars on the Six-Color System of Stebbins and Whitford*. Washington, DC: Government Printing Office.

Krüger, Karl Nicolaus Adalbert

Born **Marienberg, (Saschen, Germany, 3 December 1832**
Died **Kiel, Germany, 21 April 1896**

Stellar astronomer Karl Krüger participated in the development of two great 19th-century stellar catalogs. Krüger was educated at Berlin, and became assistant to **Friedrich Argelander** at Bonn in 1853. Krüger was immediately involved, together with Argelander and Argelander's other assistant, **Eduard Schönfeld**, in the observations that eventually led to the publication of the great *Bonnner Durchmusterung* atlas and catalog for epoch 1855.0. In 1854 Krüger was granted a Ph.D. in astronomy at Bonn. When work on the *Durchmusterung* was completed in 1862, Krüger accepted an assignment at the university observatory in Helsingfors, Russia (now Finland), and in 1876 moved to the Herzogliche Observatory in Gotha, Thuringia, Germany. In 1880, he relocated again, this time to the Kiel Observatory, where he served as professor and observatory director for the remainder of his career. Krüger observed comets and determined a number of stellar parallaxes. His principal work after leaving Bonn, however, appears to have been the zonal observations from Helsingfors and Gotha of all stars in the band +54° 55′ to + 65° 10′ for the Astronomischen Gesellschaft; a catalog of 14,680 stars in that band was published in 1890. In 1893 Krüger published a catalog of 2,153 red stars.

Thomas R. Williams

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Kūhī: Abū Sahl Wījan ibn Rustam [Wustam] al-Kūhī [al-Qūhī]

Flourished **second half of the 10th century**

Kūhī attained distinction as an astronomer who was skilled in observational instruments, and his work was well known among the astronomers and mathematicians of his age working in the Būyid domains of ʿIrāq and western Iran. Born in Tabaristan, he was supported by three kings of the Būyid Dynasty: ʿAḍud al-Dawla, Ṣamṣām al-Dawla, and Sharaf al-Dawla, whose combined reigns cover the period 962–989. Thus, Kūhī probably did most of his work in the second half of the 10th century.

Ibn al-Haytham and **Bīrūnī** knew of several of Kūhī's works, and later ʿ**Umar al-<u>Khayyām</u>** cites him as one of the "distinguished mathematicians of ʿIrāq" (Sesiano, p. 281). In 969/970 Kūhī assisted in **Ṣūfī**'s observations in Shīrāz to determine the obliquity of the ecliptic, as well as in other observations of the Sun's movement, done on the order of ʿAḍud al-Dawla. And in 988/989 he was director of the observatory that ʿAḍud's son, Sharaf al-Dawla, built in Baghdad, which was intended to observe the Sun, Moon, and the five known planets.

According to Bīrūnī, Kūhī constructed for solar observations a house whose lowest part was in the form of a segment of a sphere of diameter 25 cubits (approximately 13 m) and whose center was in the ceiling of the house. Sunlight was let in through an opening at that center point of the sphere, which was located in the roof.

Three of Kūhī's works deal directly with problems that might be called astronomical. They are: (1) *On What Is Seen of Sky and Sea* (published in Rashed), (2) *On Rising Times* (published in Berggren and Van Brummelen), and (3) *On the Distance from the Center of the Earth to the Shooting Stars* (published in Van Brummelen and Berggren). The first treats the visible horizon and shows how, knowing the height of a lighthouse on an island, one can calculate how far away its light can be seen (and related problems). In the second he shows how one can calculate the rising times and ortive amplitudes of the zodiacal signs by Menelaus's theorem. In the third he uses parallax to show how to calculate the distance to meteors. (Kūhī's technique was rediscovered in 1798 by **Johann Benzenberg** and **Heinrich Brandes** in Germany, who settled the ancient question of whether or not meteors were atmospheric phenomena.) In none of them, however, is any observational data cited, nor are any numerical examples worked. A fourth work, dealing with the astrolabe (published in Berggren), discusses the geometry of that instrument. In particular, it solves problems demanding the construction of certain lines or points of a planispheric astrolabe given other lines and points. A fifth work, applying a method for computing the direction of Mecca, which became common in astronomical works known as *zīj*es, has been ascribed to Kūhī. But the detailed computations carried out are entirely out of character with his other works and so the attribution must, for the present, be regarded as spurious.

Although Kūhī's work was studied by Islamic scholars as late as the 18th century (notably Muḥammad ibn Sirṭāq in the first half of the 14th century and Muṣṭafā Ṣidqī in the 18th century), it – like that of many of his distinguished contemporaries and successors in the eastern regions – was unknown in the west.

Len Berggren

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Kuiper, Gerard Peter

Born **Harenkarspel, the Netherlands, 7 December 1905**
Died **Mexico City, Mexico, 24 December 1973**

Dutch–American astronomer and planetary scientist Gerard P. Kuiper discovered that the atmosphere of Mars consists largely of carbon dioxide and advocated the importance of Solar System astronomy in the third quarter of the 20th century when it was generally unpopular. Kuiper also participated in the identification of some of the best mountain-top observatory sites, including Mauna Kea (Hawaii) and Cerro Tololo (Chile).

As a teenager, Kuiper was interested in astronomy and had good-enough eyesight to produce a sketch of the Pleiades including stars that are a factor of four fainter than most people can see without a telescope. He earned a B.Sc. in 1927 and a Ph.D. in 1933 from Leiden University, with a thesis on binary stars carried out under **Ejnar Hertzprung**. Among the best known of his own students in turn were Thomas Gehrels, Tobias Owen, and Carl Sagan, all of whom made important contributions to planetary astronomy, especially with the use of infrared observations, another of Kuiper's early interests.

Following his Ph.D., Kuiper became a fellow at Lick Observatory (1933–1935), moved on to Harvard (1935–1936), and was appointed to an assistant professorship at the University of Chicago and Yerkes Observatory in 1936. Kuiper married Sarah Parker Fuller (by whom he had two children) in 1936 and became a US citizen in 1937. He became full professor in 1943 and headed west to the University of Arizona in 1960 as the founder of the Lunar and Planetary Lab [LPL] there, from the directorship of which he resigned a year before his death. His war work was initially as an operations analyst at Eighth Air Force Headquarters in 1944, and he was part of the Alsos debriefing mission to formerly Nazi Europe in 1945.

Kuiper's early work focused on binary stars; he was the first to attempt a statistical description of the distribution of binary orbit periods and mass ratios. He suspected (correctly) an almost uniform distribution over the entire period range, from stars that touch each other (for which he coined the name "contact binaries") to ones almost a parsec apart, and a mass ratio distribution that was a direct reflection of the fact that little stars are much commoner than big ones. Kuiper also did one of the first quantitative estimates of the dependence of star brightness on mass and calculated the relationship (called bolometric correction) between the total brightness of a star and the amount of luminosity in the wavelength band we can see. He and, separately, **Willem Luyten** were responsible for the discovery of most of the white dwarfs found until **Jesse Greenstein** took up the problem in the 1960s; Kuiper was instrumental in recognizing that the white dwarfs, like normal stars, could be classified by the elements whose absorption features appear in their spectra.

During his time at Chicago, Kuiper interacted with **Otto Struve**, **Subrahmanyan Chandrasekhar**, **Gerhard Herzberg**, and **Harold Urey,** and so gradually turned his attention from binary stars to their formation and on to the interdisciplinary topic of the formation of the Solar System. He concluded (probably wrongly) that planet formation is the low-mass extreme of the same process that makes double stars. Kuiper was involved in building the 82-in. reflector at the new McDonald Observatory in west Texas and, with it, discovered methane in the atmosphere of Titan (Saturn's largest satellite) in 1944 and carbon dioxide in the atmosphere of Mars in 1947. He also discovered one satellite each of Neptune (Nereid) and Uranus (Miranda). Many of these accomplishments, and his later survey of minor planets, were undertaken using a Cashman lead sulfide cell (developed during World War II) as an infrared detector.

Kuiper assumed, along with most of his contemporaries, that there would be very few planets or minor planets beyond the orbit of Neptune, while, in contrast, Frederick Leonard, Kenneth Edgeworth, **Fred Whipple**, and A. G. W. Cameron thought that there might be a great many residual planetesimals 30–50 AU from the Sun. Nevertheless, the name Kuiper belt (less often, Kuiper–Edgeworth belt) is invariably attached to these objects and their location.

The LPL, with Whipple's group at Harvard University, became one of the two major planetary science groups in the United States. Increasing friction with his Chicago colleagues over how credit for various discoveries about the Moon and planets should be apportioned was part of the reason Kuiper left the University of Chicago and Yerkes Observatory. He remained the LPL director until a year before his death.

Kuiper and his colleagues investigated planetary atmospheres, prepared an atlas of the Moon (which contributed to the choice of Apollo program landing sites), and pioneered infrared planetary studies from high-altitude aircraft. The American long-lived follow-on mission to these initial studies was called the Kuiper Airborne Observatory. Another of his legacies to later generations of astronomers was the commissioning and overall editing, first, of a four-volume series called *The Solar System* and, later, of a nine-volume (only eight of which were ever completed, shortly after Kuiper's death) compendium covering all of astronomy, from telescopes to cosmology. He was a member of the United States National Academy of Sciences and of the American Academy of Arts and Sciences as well as a foreign associate of the Royal Astronomical Society. Kuiper died of a heart attack while attending an astronomical meeting.

Daniel W. E. Green

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Kulik, Leonid Alexyevich

Born **Tartu, (Estonia), 19 August 1883**
Died **Spas-Demensk near Smolensk, (Russia), 14 April 1942**

Leonid Kulik was a leading Soviet meteoriticist who is best known for his investigations of the 1908 Tunguska, Siberia, impact site. His father was a physician. Kulik's secondary education was completed in 1903 at the Gymnasium in the town of Troitsk, Orenburg Province, in the Ural Mountains, where he won a gold medal. He then pursued an education at the Institute of Forestry in Saint Petersburg until he was inducted into military service in 1904 and sent to Kazan on the Volga River. On his own initiative, he attended lectures at the Faculty of Physics and Mathematics at Kazan University. In 1910, Kulik was arrested for revolutionary activities but, after serving a short time in prison, was sent to the Ilmen region of the Urals. During the next 2 years (1911–1912), he was paroled to work in the Forestry Department on the condition of making frequent reports to the police chief in the town of Zlatoust. In 1912, Kulik married Lidiya Ivanovna; both later served on the scientific staff of the Mineralogical Museum of the Academy of Sciences in Saint Petersburg. In the course of his fieldwork, Kulik had the good fortune to meet and work with a leading scientist, Vladimir Ivanovich Vernadsky, who became known as the father of geochemistry in the USSR. With the outbreak of war, Kulik joined the army and served on the western front.

After the October 1917 Revolution, Kulik's record of arrest under the Czarist regime redounded to his advantage. Early in 1918, he went to the Soviet Academy of Sciences in Petrograd and started working on meteorites. Later that same year, Kulik led an expedition, organized by the academy, to investigate the fall of a stony meteorite on 27 February 1918, near the town of Kashin, in the province of Tver, a short distance north of Moscow. He returned with a 122-kg specimen of the Glasatovo chondrite, named for the village where it fell.

In 1921, the Mineralogical Museum of the Academy of Sciences in Petrograd established a meteorite section with Vernadsky as director. Vernadsky assigned Kulik to lead a 2-year expedition to gather information on the fall of a giant meteorite witnessed in Siberia in June 1908. Reports in provincial newspapers had described a brilliant fireball, visible over a vast area, moving from approximately the south to the north, accompanied by deafening explosions and a great trembling of the ground when it struck the Earth. Using a railroad car designated for the purpose, Kulik visited many places in Siberia and gathered eyewitness accounts. One story implied that the meteorite had landed at Tomsk in western Siberia. Kulik found no meteorite at Tomsk, but learned that the fireball had passed over the Yenesei Province and landed somewhere near the mouth of the Podkamennaya Tunguska River, a site so remote that he could not visit it on that trip.

Throughout his travels, Kulik collected reports of numerous meteorite falls, and sometimes obtained specimens. He made special efforts to educate the people he met about meteorites, and enlisted many volunteers to serve as corresponding observers who would send reports back to the institute on a regular basis. During the 1920s, Kulik issued updated instructions to this network, which grew in membership and in the volume of reports and specimens that were returned to Petrograd each year.

In 1927, Kulik led the first of several expeditions to the Tunguska area to investigate the 1908 fall. From the remote fur-trading station of Vanovara in eastern Siberia, he traveled by horse and reindeer into the deep forest. Kulik was led by local guides, some of whom had witnessed the event at fairly close range. Even after 19 years, the destruction he encountered was awesome beyond all expectations. Kulik found that a vast area of the forest had been uprooted and flattened, with treetops fanning outward. Only on later expeditions did he determine that the fallen trees pointed radially away from the center of an explosion. The tree roots faced a swampy area of low mounds and peat bogs pocked with rounded holes, up to a few dozen meters across, that Kulik believed were the craters made by a swarm of impacting meteorites.

In 1928 and again in 1929/1930, Kulik led two more arduous expeditions to Tunguska in an effort to excavate the water-filled holes and recover the meteorites. He directed the draining and trenching of one large depression, and the boring with hand augers into others. Kulik also conducted geodetic and magnetic surveys of the entire area. But all to no avail; he found no meteorites in the ground or on the surface. However, photographs of the flattened forest, taken on his expeditions, caused a sensation at home and abroad.

Back in Petrograd, Kulik argued for an aerial survey of the Tunguska region. The first attempt, made in 1930, was postponed twice for logistical problems. Faced with delays, Kulik conducted other inquiries. In 1933, he investigated a shower of stony meteorites that occurred on 26 December at Pervomaiskii Poselok in the Vladimir Province of Russia. It was seen over such a wide area that Kulik determined the approximate site of the fall from the reports sent to the Meteorite Institute. He visited the area immediately and obtained about 16 kg of specimens from local citizens. Kulik did not find the strewn field right away, but used a theodolite to calculate the trajectory of the fireball. After the snow melted, he went directly to the strewn field, aided by a group of schoolboys, and collected 97 stones weighing a total of 50 kg. This was the first known instance in which an instrumental calculation revealed the site of a meteorite fall.

In 1937, during an attempted aerial survey of Tunguska, the plane crash-landed but with no harm done to Kulik or the other passengers. Finally, in 1938, the aerial survey successfully revealed that the uprooted trees lay in an elliptical area with a center of devastation some 12 to 15 km across in the northwestern portion of the ellipse. The total affected area was 250 km^2. Kulik returned to the site in the following year to correlate the aerial photographs with geodetic stations he had set up in the region. Further studies, however, were prevented by the onset of World War II.

When Kulik investigated the Tunguska site, only a few scientists favored a meteorite impact as the origin of craters found on the Earth or Moon. However, Kulik's summary of eyewitness accounts of the fireball, together with his photographs of the devastation at the site, provided clear evidence that a large extraterrestrial body had wreaked destruction on the Earth in historic times. This finding prompted many scientists to take a new look at the possibilities of meteorite impacts as *geological processes*.

Kulik found no crater and no meteorites at Tunguska because, like most scientists of the time, he did not understand the explosive potential of meteorites moving through the Earth's atmosphere at cosmic velocities. Today, astronomers and meteoriticists agree that the incoming body exploded in the atmosphere over Tunguska without reaching the ground and without depositing any meteorite fragments. The remaining point of contention is whether that body was a fragment of a comet or a friable asteroid.

By the start of World War II, Kulik held the position of curator of meteorites at the Soviet Academy of Sciences, a well-earned appointment that recognized his leading role in promoting the growth and documentation of the Soviet Union's collection of meteorites. He was the first person to serve as the scientific secretary of the Academy's Committee on Meteorites, which was chaired by Vernadsky. Kulik retained his civilian status because of weak eyesight. Nonetheless, he voluntarily joined the so called minutemen and was captured by the German army and put into a camp. He wrote a series of letters describing his daily life in the camp, where he did some paramedical work. Kulik contracted typhus and died.

Ursula B. Marvin

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Kunicia, Maria

➜ **Cunitz [Cunitia,Cunitiae], Maria**

Kuo Shou-ching

➜ **Guo Shoujing**

Küstner, Karl Friedrich

Born **Görlitz, (Sachsen, Germany), 22 August 1856**
Died **Mehlem, (Nordrhein-Westfalen), Germany, 15 October 1936**

As a meridian observer, Friedrich Küstner achieved an outstanding reputation for the precision and accuracy of his own observations as well as for his careful reconsideration of historical observations. He was the first astronomer to measure the solar parallax using the radial velocities of stars measured at different times of the year. The son of a master bricklayer, Küstner first became familiar with practical astronomy when he was a student at Strassburg University, where he received his Doctor of Philosophy in 1879. While there, he was influenced strongly by **Friedrich Winnecke**. Shortly after finishing school, Küstner began work at the office of the *Berliner Jahrbuch*. There, he mostly worked on computing orbits of minor planets and on the redetermination of the constant of aberration. In 1882, Küstner was selected by **Arthur Auwers** to act as his first assistant on the transit of Venus expedition to Puntas Arenas, Argentina.

In 1884, Küstner was appointed Observator of the Berlin Observatory. During his tenure there, he returned to the problem of determining the constant of aberration. The anomalous data obtained from his observations convinced him that the latitude of the telescope had changed. With further observations over the course of a year, Küstner proved conclusively that the variation of latitude occurred on a different frequency than that predicted by **Leonhard Euler**. Küstner's work allowed **Seth Chandler** to reexamine the entire problem using his own observations, Küstner's, and other zenith observation data sets to determine the correct frequency, later confirmed theoretically by **Simon Newcomb.**

In 1891, Küstner became a Professor of Astronomy and the Director of the Bonn Observatory, succeeding **Eduard Schönfeld**. A couple of years after this, he began work on his catalog of 10,663 stars. This catalog included stars between the celestial equator and declination +51°, using his own observations made with a 6-in. Repsold meridian circle. It was considered the most accurate catalog of its kind at the time of its completion, in part because of his work reducing errors in positions due to stellar magnitude by making all observations reduced to a standard magnitude of 8.5. Using a 12-in. photographic refractor along with a three-prism spectrograph, Küstner also made observations of the radial velocities of stars. This information, combined with his earlier work on fundamental positions of stars and the known velocity of light, length of the year, and radius of the Earth, allowed him to determine the speed of the Earth in its orbit, the aberration constant and the solar parallax.

Küstner received the Gold Medal from the Royal Astronomical Society for his star catalog, his work in the determination of the aberration constant from line-of-sight motions of stars, and for his detection of the variation of latitude. He also received the Bradley Medal of the Prussian Academy of Sciences. At the 1928 International Astronomical Union Meeting in Leiden, the Netherlands, Küstner was conferred an honorary degree. He was a member of the Royal Astronomical Society and the United States National Academy of Science.

In 1887, Küstner married the daughter of a Hamburg sculptor named Börner. They had two children. Their son was a U-boat commander in World War I who was listed as missing. After his retirement, Küstner was cared for by his daughter.

Brian Luzum

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L

Labbān, Kushyār

➜ **Ibn Labbān, Kūshyār**

La Caille [Lacaille], Nicolas-Louis de

Born **Rumigny, (Ardennes), France, 15 May 1713**
Died **Paris, France, 21 March 1762**

Nicolas de Lacaille (as he signed his name) was one of the greatest observers of the 18th century and a pioneer in mapping the southern sky. His father served the Duchess of Vendôme as chief huntsman, but he devoted his spare time to the study of natural science and mechanics. After his father died, the young Lacaille put himself under the patronage of the Duke of Bourbon, wishing to study theology to be able to take holy orders. After becoming deacon, however, he forsook the ecclesiastical career and turned all his thoughts to science.

Self-taught in astronomy and mathematics, Lacaille moved to Paris in 1735. There he gained the friendship and the esteem of **Jacques Cassini**, director of the Paris Observatory. In 1736 Lacaille began to work at the observatory, where he was officially engaged 3 years later. This allowed him to meet the most important astronomers of the time. In 1740, Lacaille was appointed professor of mathematics at the prestigious Collège Mazarin, and in 1741 he was admitted to the membership of the Académie royale des sciences. In this period, in order to fulfil his professorial duties, Lacaille wrote several handbooks (entitled *Leçons élémentaires*) that met with a great success and were translated into many languages, even into Latin: They covered mathematics (first edition in 1741), mechanics (1743), geometrical and physical astronomy (1746), and optics (1750). Additionally, beginning in 1745, Lacaille took care of the yearly edition of the *Ephémérides*.

Lacaille's first important astronomical experience was the measurement of the arc of the meridian. In 1739 he had taken part, under the direction of **Giovanni Maraldi**, in the survey of the French southwest coasts, from Nantes to Bayonne. Thanks to the skill he showed on this occasion, he was called to participate in the verification of the Paris meridian, and the results of this work were published in 1743 under the name of Jacques Cassini. Processing all the data he had collected, Lacaille compared several meridian arcs and was able to determine that their extension decreased from the Equator to the poles. This outcome helped to solve definitively the famous question about the Earth's shape, confirming that the Earth is squashed like an orange and not stretched like a lemon. Lacaille was not the only scientist who drew this conclusion, but he was admired since he could do this by considering only 4° of latitude.

From the end of 1750 to June 1754, Lacaille led a scientific expedition to the Cape of Good Hope and drew the first geodetic map of Mauritius. He set up his observatory beneath the slopes of Table Mountain near Cape Town. In only 2 years' time he measured the coordinates of 9,766 stars, probably using a one-half in. diameter telescope. Lacaille drew the first complete map of the southern stars, which would be published by the Académie royale des sciences in 1756: On this map he marked 14 new constellations, which would be rapidly accepted by the astronomers of the entire world and which are still in use in the official constellations list. Besides creating these new constellations, Lacaille broke up the large classical constellation of Argo Navis into its component parts: Carina (Keel), Puppis (Stern), and Vela (Sail).

Lacaille also cataloged 42 nebulae and clusters of the Southern Hemisphere. His list was published in 1755, 16 years before the first installment of **Charles Messier**'s catalog of nebulae and clusters was printed. Lacaille divided his "nebulous stars" into three classes: "Nebulosities not accompanied by stars" (class 1), "Nebulosities due to clusters" (class 2), and "Stars accompanied by nebulosity" (class 3).

At the Cape, Lacaille also turned his attention to the planets. In particular, he made careful observations of the position of the Moon, Venus, and Mars: By comparing his data with the records made in the same time by **Joseph de Lalande** from Berlin, he could calculate, with the parallax method, more accurate values for the distances of these bodies from the Earth.

Additionally, Lacaille occupied himself with the so called longitude problem, which had attracted astronomers' attention for more than two centuries. He polished the "method of the Moon" developed by **John Flamsteed** and thought up some ingenious graphic systems, which allowed him to simplify the toilful calculations required to find the longitude.

After returning to Paris, Lacaille resumed his work at the Collège Mazarin, where he installed a new telescope. His publications were forerunners of modern compilations of stellar catalogs and planetary tables. In 1757, he sent to the press his *Fundamenta Astronomiae*, with a catalog of about 400 bright stars: For the first time star positions were corrected by taking into account aberration and nutation. In 1758, Lacaille published the *Tables solaires*, in which he was the first to mark lunar and planetary perturbations as well as aberration and nutation. These two books would be very important for the increments in accuracy they brought about, and for the inspiration they gave to later astronomers.

Lacaille also edited the *Traité d'optique sur la gradation de la lumière*, whose manuscript was bequeathed him by **Pierre Bouguer**, and took care of a new edition of the *Traité du navire* by the same author. In recognition of his work, many scientific institutions appointed him honorary member: the academies of Saint Petersburg, Berlin, and Stockholm, the Royal Society of London and the Royal Society of Göttingen, and the Institute of Bologna.

In 1761, Lacaille observed the transit of Venus. In the same year, he determined the distance of the Moon, taking into account, for the first time in history, the nonsphericity of the Earth.

A little later, a strong fit of gout took over Lacaille, but he did not stop his work. The illness, however, became worse, and Lacaille died. His friend and colleague Maraldi collected his manuscripts and published them in 1763 under the title of *Coelum australe stelliferum* (Star catalog of the southern sky). In the same year his travel diary, the *Journal historique du voyage fait au Cap de Bonne-Espérance*, was sent to the press. At the time, everybody considered Lacaille's death as a great loss for astronomy and science: Lalande expressed his admiration for the large amount of observations and calculations made by Lacaille, and **Jean Delambre** noted that Lacaille's "astronomical life" lasted only 27 years.

Marco Murara

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Lacchini, Giovanni Battista

Born **Faenza, (Emilia-Romagna), Italy, 20 May 1884**
Died **Italy, 6 January 1967**

Originally an Italian postal worker, Giovanni Lacchini became a professional astronomer when a special position was legislated just for him. Lacchini's status was due to his enthusiasm for variable stars: He made observations of variables (53,000+) from locations all over Italy – even from moving trains between stations! Lacchini's skill was such that he could estimate the brightness of a star visually to a tenth of a magnitude, using only one comparison star. He was the first international member of the American Association of variable star observers [AAVSO] and was elected vice president of that organization.

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Lacroute, Pierre

Born **Dijon, Côte d' Or, France, 12 January 1906**
Died **Verrières, Aveyron, France, 14 January 1993**

Strasbourg Observatory's Pierre Lacroute is credited with the idea behind the successful HIPPARCOS mission: trigonometric parallax measurements from space.

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Lagrange, Joseph Louis

Born **Turin, (Italy), 25 January 1736**
Died **Paris, France, 10 April 1813**

Joseph Lagrange made numerous, significant contributions to mathematics and to celestial mechanics (Lagrangian points), especially through his invention of the calculus of variations. A particular combination of the variables in a dynamical system is called the Lagrangian. He was the son of Giuseppe Francesco Lodovico Lagrangia and Teresa Grosso. Lagrange found mathematics initially uninteresting but became attracted to it due to **Edmond Halley**'s works. He lived in Turin until 1766, when he moved to Berlin to work at the Academy of Sciences. He stayed there until 1787, when he moved to Paris, where he remained until his death.

Lagrange's mathematical career began in 1754 with a paper submitted to **Leonhard Euler** at the Berlin academy on the calculus of variations. Euler passed copies of Lagrange's work to **Pierre de Maupertuis**, who offered Lagrange a position at the Academy of Sciences at Berlin. Lagrange declined, though he was made an associate foreign member. Meanwhile, with others, Lagrange co–founded the Royal Academy of Sciences in Turin in 1757.

Lagrange applied his considerable talents to many of the unsolved problems in celestial mechanics. For the prize question of 1764, the Paris Academy of Sciences asked for an explanation of why the Moon's rotational and orbital periods coincide, thereby always showing the same face to us. The prize committee awarded the prize to Lagrange, the first of five times he would win a prize competition, a record surpassed only by Euler. Lagrange's winning solution included the first complete mathematical account of the phenomenon of libration.

The 1766 prize question concerned the explanation of the various inequalities in the motions of the four Galilean satellites of Jupiter. If two bodies were alone in the Universe, they would orbit each other along an unchanging elliptical orbit, but the real case is more complex; the gravitational perturbations of the Sun, planets, and satellites mean that orbital parameters constantly vary under changing gravitational influences. These variations or inequalities fall into two categories: periodic, which forever oscillate about a mean value, and secular, which increase without bound. Lagrange's submission won the prize, establishing him as one of the foremost mathematicians in Europe. Shortly afterward, **Jean d'Alembert** offered Euler's position at Berlin to Lagrange when Euler left for the Russian Academy of Sciences. Thus, in October 1766, Lagrange arrived in Berlin.

Jupiter and its satellites are an example of an *n*-body problem. The general method of approach is to solve a corresponding 2-body problem, and then take into account the perturbations caused by the addition of bodies. The motion of the Moon is even more difficult, for the Sun's perturbing effect on the Moon's motion about the Earth is far higher than any other perturbations in the Solar System. In 1770, the academy, dissatisfied with existing tables of the Moon's position, offered a prize for a new theory of the Moon and thus a new method of creating more accurate tables of the Moon's position, which in turn could be used to solve the longitude problem. None of the entries received by the academy were deemed satisfactory, so in 1772 the academy posed the question again, this time with a double prize of 5,000 florins. Both Lagrange and Euler submitted winning papers, and shared the double prize.

In the first section of this paper, Lagrange made one of his most celebrated contributions to celestial mechanics. He found five points in a 2-body system where a third body, assumed not to gravitationally influence the other two, could be placed so as to remain in a stable position relative to the other two. These five points are today known as the Lagrangian points closely related is the inner Lagrangian Surface for instance, in a binary star systems, on which material can flow freely from one star to the other (also called a Roche lobe).

Despite their success, neither Euler nor Lagrange could explain a phenomenon noted by Halley. Observations from the time of **Ptolemy** could not be reconciled with contemporary observations unless one assumed that the Moon's mean motion was undergoing a steady acceleration. In March 1772, d'Alembert suggested to Lagrange that the lunar acceleration might be the subject of the next prize question. Lagrange's analysis showed that the perturbations caused by the planets were periodic in nature; hence, any variation they caused was also periodic, so they could not produce a secular variation. He concluded that because the secular acceleration could not be accounted for mathematically, then it had to be an observational error. Lagrange won the prize, though it should be pointed out that he was not entirely correct. A later analysis by **Pierre de Laplace** showed that very slow (but periodic) changes in the eccentricity of the Earth's orbit were the source of very long period (hence, apparently secular) variations in the Moon's mean motion.

The next prize question posed by the academy, for 1776, concerned the perturbation of the orbits of the comets. Lagrange began to compose an entry, but shortly afterward withdrew from the contest. The academy found none of the entries worthy of an award, so once again, they repeated the question with a double prize in 1780. This time, Lagrange won the double prize himself.

When Lagrange withdrew from the 1776 contest, he found himself involved in a far more important question: an examination of the orbits of the planets. An elliptical orbit has five main parameters: the inclination of the orbit to the plane of the ecliptic, the eccentricity, the semimajor axis, the position of the nodes, and the position of the aphelion. Gravitational perturbations vary these five parameters. Of the five, two (the position of the nodes and the aphelion positions) could be varied any amount without seriously affecting the constitution of the Solar System, but this was not true of the eccentricity, inclination, or semimajor axis; vary these too greatly, and the orderly march of the planets around the Sun would be disrupted. Hence, the question arose of the long-term stability of the Solar System.

In 1774, Lagrange had shown that the inclinations of the planetary orbits undergo only periodic variations. Lagrange's paper, sent to the Paris academy, was given to Laplace to referee. Laplace applied Lagrange's method and showed that the eccentricities likewise underwent only periodic variations. Moreover, Laplace managed to rush his own work into print *before* Lagrange's (though giving credit to Lagrange for having developed the method he used). Not surprisingly, Lagrange submitted no more papers to the academy.

Lagrange's crowning result thus appeared in the 1776 *Memoirs* for the Berlin Academy of Sciences. Lagrange showed that the semimajor axes of the planetary orbits, like the inclinations and eccentricities, underwent only periodic variations, answering positively the question of the stability of the Solar System.

By 1787, Lagrange's position at Berlin was more of a burden than a joy. He had married his cousin, Vittori Conti, in September 1767, but they had no children. She died in 1783 after some years of poor health. Lagrange's health, too, was far from perfect. Frederick the Great died in 1786, and after his death the prestige and position of Prussia began a long decline. Lagrange accepted an offer from the Paris academy to become a member, particularly since the offer specifically excluded teaching as one of his responsibilities. Lagrange left Berlin on 18 May 1787. In 1792 Lagrange married again, this time to Renée-François-Adélaide le Monnier (daughter of **Pierre le Monnier**). The marriage contract was signed on 3 June by the royal family, one of the last official acts of the doomed Bourbons.

Lagrange himself managed to survive the Revolution, though at times his fate was in doubt. In September 1793, at the height of the Reign of Terror, an order was issued for the arrest of all enemy aliens and the seizure of their property. A special dispensation was arranged for Lagrange at the behest of chemist Antoine Lavoisier, who would himself be executed by the radicals a few months later. Many schools were closed down during the first years of the Revolution, and in an attempt to restore higher learning, the École Polytechnique and École Normale were established; Lagrange taught at both. The École Normale closed down after just 3 months of instruction, but the École Polytechnique survived the revolutions and beyond. Napoleon, who himself was well aware of the prestige associated with top scientists, showered honors on Lagrange and others: Lagrange was made a Senator, then a Grand Officer in the Legion of Honor, and then a Count of the Empire. Finally, on 3 April 1813, Napoleon inducted Lagrange as a Grand Croix of the Order of the Reunion. A week later Lagrange died.

Jeff Suzuki

Alternate name

Lagrangia, Giuseppe Lodovico

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Lagrangia, Giuseppe Lodovico

➲ **Lagrange, Joseph Louis**

Lalande, Joseph-Jérôme

Born **Bourg-en-Bresse, (Ain), France, 11 July 1732**
Died **Paris, France, 4 April 1807**

Lalande organized and reduced observations from the 1769 French transit-of-Venus expeditions, prepared a great star catalog and important astronomical bibliography, and taught many astronomers.

Lalande's father was Pierre Lefrançois, director of a tobacco warehouse, who married Marie-Anne-Gabrielle Monchinet. Their son was educated by the Jesuits at Bourg and then at Lyons. Sent to Paris to study law, he frequented the observatory of **Joseph Delisle** at the Hôtel de Cluny and attended his lectures and those of **Pierre–Charles Le Monnier** at the Collège royal (now Collège de France). Then he named himself Lalande. A bachelor, in his 50s he adopted his nephew Michel Lefrançois, who married Amélie Harlay, whom he considered both niece and daughter.

In 1751, **Nicolas de La Caille** was at the Cape of Good Hope to measure the lunar parallax, which requires simultaneous measurements. The most advantageous other site being in Berlin, Le Monnier proposed himself as an observer but had his young pupil Lalande carry it out. At Berlin, Lalande was well received by Frederik II. He observed the Moon from 29 November 1751 to 1 September 1752, studied analysis with **Leonhard Euler**, and met the philosophers of the King of Prussia. He became a member of the Berlin Academy of Sciences, and, upon his return to Paris, a member of the Academy of Sciences there as *astronome adjoint* on 4 February 1753. In 1772, Lalande was named *pensionnaire*. He published three memoirs on the lunar parallax in *Mémoires de l'Académie* for 1752, 1753, and 1756.

Delisle sent instructions to his numerous correspondents for observing the transit of Mercury on 6 May 1753. Lalande observed it with Le Monnier at the castle of Meudon (future observatory of **Jules Janssen**) and used a heliometer designed by **Pierre Bouguer**. On Lacaille's return, Lalande adopted his methods rather than those of Le Monnier, leading to a quarrel and a falling out. Lalande remained a friend of Delisle, who offered him in 1754 the dome of the Luxembourg palace where he used his heliometer for determining the diameters of the Moon and the Sun. Lalande observed there for 10 years.

In 1758, **Alexis Clairaut** calculated the date of the return of the comet of 1682 (IP/Halley) with the help of Lalande and **Nicole Lepaute**. Lalande published (1759) a series of tables of Halley's Comet and the history of this comet.

Delisle sent out instructions again for observations of the 6 June 1761 transit of Venus, which Lalande observed at the Luxembourg palace.

Lalande obtained the editorship of the *Connaissance des Temps*, which he transformed, including information useful for navigation. Lalande composed 16 volumes from 1760 to 1775. After becoming a *pensionnaire* of the academy, he left the journal, but he took it up again from 1794 until his death.

In 1762, Delisle, who wished to retire, handed over his astronomy courses at the Collège royal to Lalande, who was named to the chair upon Delisle's death in 1768. In 1764, Lalande published his influential *Astronomie*, which served to instruct astronomers for many years. For his pupils and his own work, he made several observatories available: his own at the Collège Mazarin (now Institut de France) from 1764 to 1806; at his home Palais Royal square from 1770 to 1775; at the Collège Royal, where he settled in 1775; and later at the École militaire.

At the Collège de France, Lalande became a famous teacher, instructing **Jean–Baptiste Delambre**, **Pierre Méchain**, and **Giuseppe Piazzi**. He also taught navigational astronomy, and published (1793) navigational time tables calculated by his niece/daughter. She inspired him to write *Astronomie des Dam*es, published in 1785.

For the transit of Venus on 3 June 1769, Lalande developed Delisle's method of computing solar parallax, and sent instructions and maps. He refused to travel, reserving for himself the analysis of the observations he hoped to receive from his correspondents. In 1770, he deduced a solar parallax of 8.5″ to 8.75″.

With his observations and those of his correspondents and pupils, Lalande established orbits and tables of planets from 1755 to 1796. In 1789, he observed the Sun at the solstice, just as La Caille had done 40 years ago at the same observatory with the same instrument; Lalande calculated that the obliquity of the ecliptic is diminishing by 38′ each century.

In 1783, Lalande started his last great project: to establish a catalog of 50,000 stars down to the ninth magnitude. Observations were made until 1785 at the observatory of the École militaire by his pupil Dagelet, now teacher at this school. After the destruction of this observatory, Lalande achieved its reconstruction in 1788, when his nephew **Michel Lefrançois-Lalande** became its main observer. Lalande published his catalog in *Histoire céleste* (1801), which **Heinrich Olbers** declared one of the most important productions of the 18th century.

Lalande often expressed interest in the history of astronomy. In *Connaissance des Temps*, he published the astronomical history of the past year, and gathered those articles in 1803 in *Bibliographie astronomique avec histoire de l'astronomie de 1781–1802*. This huge volume, the printing of which was funded by the government, is an important bibliographical source.

On 10 August 1792, Lalande saved the lives of several nobles and priests by hiding them in his observatory of the Collège Mazarin. In August 1793, during the Revolution, the academies were suppressed in France. In 1795, after the Terror, the Convention created the Bureau des Longitudes and reestablished the Paris academies gathered in the Institut National. Lalande was the first astronomer named at the Bureau, of which he became the secretary; he was also the delegated director of the Paris Observatory until the return of Mechain. In February 1793, when the Republican calendar was established, Lalande had to adopt it in *Connaissance des Temps*, but by 1801, he publicly wished the return of the Gregorian calendar, which was reestablished in France on 1 January 1806.

Lalande liked to travel. In France, he visited many of his correspondents and spent a few months in Bourg nearly every year. He traveled to England, Switzerland, Holland, Germany, and Italy and published a volume on his travel in Italy. He ascended balloons to study the scintillation of stars and hoped to reach Gotha by such means. In 1798, in Gotha, Lalande presented the newly devised metric system to German astronomers gathered by **János von Zach**.

Lalande became a freemason, probably in Bourg-en-Bresse, around 1770. In 1776, he founded the Lodge of Nine Sisters, which received Voltaire in 1778 and of which Benjamin Franklin was a member. In the 1805 supplement of *Dictionnaire des Athées* of Sylvain Maréchal, Lalande attacked those who bloody the Earth by war. This attracted the attention of Napoleon, who ordered the Academy of Sciences to forbid him from publishing.

Lalande updated the astronomical articles for the new *Encyclopédie méthodique*, published more than 150 memoirs, and helped publish the work of French and foreign scientists, including LaCaille, Bouguer, Jean Montucla, **John Flamsteed**, Jesse Ramsden, and others. He was a member of the academies of London, Berlin, Petersburg, Stockholm, and Bologna.

Lalande was both impatient and generous with correspondents and pupils. He enjoyed attention and glory, receiving it in life and in death; his statue is displayed with one of **Giovanni Cassini** among the 86 illustrious men installed in the middle of the 19th century on the Louvre's façade in the court of Napoléon.

Simone Dumont

Alternate names

de la Lande, Joseph-Jérôme
Lefrançois de la Lande, Joseph-Jérôme

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Lalla

Flourished **Lāṭa region, (Gujarat, India), 8th century**

Lalla was a Hindu astronomer who attempted to synthesize two of the principal schools of astronomical thought that were active during the classical period (late 5th to 12th centuries). Despite the significance of Lalla's work, very little is known about his life. According to very brief autobiographical comments, he was a member of a Brāhmaṇa family, the son of Trivikrama Bhaṭṭa, and the grandson of Taladhvaja. Lalla did not record any dates relating to his life or work in his surviving treatises. He is generally placed in the middle of the 8th century on the basis of his borrowings from earlier authors and those of later authors from him. Lalla's geographical location has been assigned to the Lāṭa region on the strength of some allusions in his verses, and a remark by one of his commentators that these probably reflected "regional chauvinism on Lalla's part." Only two of Lalla's works are known to be extant.

The *Śiṣyadhīvṛddhidatantra* (Treatise for increasing the intelligence of students) is one of the first major Sanskrit astronomical treatises known from the period following the 7th-century works of **Brahmagupta** and **Bhāskara I**. It generally treats the same astronomical subject matter and demonstrates the same computational techniques as earlier authors, although there are some significant innovations. Lalla's treatise offers a partial compromise between the rival astronomical schools of his predecessors, **Āryabhaṭa I** and Brahmagupta. Lalla is avowedly a follower of the former, but combines parameters and techniques from both. He borrows the titles from two chapters of the *Āryabhaṭīya* ("Computation" and "The Sphere") and applies them to sections of his own work. The first of these covers standard astronomical tasks, including the mathematical prediction of ominous events such as eclipses and celestial conjunctions.

Lalla's section on "The sphere" is more concerned with general elucidations of the terrestrial and celestial spheres than with the immediate demands of astronomical computation. Nonetheless, Lalla insists on the necessity of understanding the larger mathematical picture as well as the application of formulas: "The learned say that spherics is [essential] for calculation." Both his textual arrangement and arguments were frequently copied by later astronomers. His chapter entitled "False knowledge" contains a defense of cosmology against criticism on physical and scriptural grounds. In the 12th century, **Bhāskara II** wrote a commentary on Lalla's *Śiṣyadhīvṛddhidatantra*.

The *Jyotiṣaratnakośa* (Treasury of Jewels) is Lalla's treatise on catarchic astrology. It represents the earliest known Sanskrit astrological work for determining auspicious and inauspicious times. No edition of that work has been published; the several known manuscripts are incomplete.

Kim Plofker

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Lallemand, André

Born **Cirey, Haute-Saône, France, 29 September 1904**
Died **Paris, France, 24 March 1978**

While he contributed chiefly to the development and application of photomultipliers, André Lallemand also played important roles in the construction and instrumentation of French telescopes.

Lallemand was the son of Louis and Lucie Lallemand; his father was a primary-school teacher. Lallemand's career in astronomy began in 1925 at the Strasbourg Observatory, where he served as an assistant to **Ernest Esclangon**. He qualified as a schoolteacher in the physical sciences in 1927 and taught at a high school in Haguenau, near Strasbourg, for a year. His doctoral research, which examined the magnetic properties of different elements of the iron family, was completed under Pierre Weiss at the Strasbourg Physical Institute. There, Lallemand acquired the experimental techniques that were essential for his later research on electronic detectors and amplifiers. He married Suzanne Ancel in 1928; the couple had two sons.

In 1928, Lallemand returned to the Strasbourg Observatory as *aide-astronome*, the level above an assistant. He devoted his energies to the improvement of astronomical observation methods. His infrared photographs of the solar corona, taken during an eclipse observed at Poulo Condore, Vietnam in 1929, were in accord with the expected diffusion of light by photospheric electrons.

Lallemand's interests then turned to astronomical photometry. In 1934, realization of the first photoelectric imaging devices led him to imagine what he called the "electronic telescope," now known as the "electronic camera." An optical image was first projected onto a photoelectric cell. The emitted electrons were then accelerated and refocused onto a photographic plate. The outbreak of World War II interrupted but also intensified research on these imaging devices. For several years, he and other scientists from the University of Strasbourg were moved to Clermont-Ferrand for defense-related work. In 1943, Lallemand accepted a joint appointment at the Paris Observatory and established a laboratory dedicated to improving photoelectric imaging devices for astrophysical observations.

In the 1950s, Lallemand collaborated on detector developments with Maurice Duchesne. The pair obtained a 100-fold gain in sensitivity as compared to ordinary photography. After 1952, numerous astronomical observations were made with this instrument, especially at the Haute-Provence Observatory. In 1953, Lallemand was named a senior astronomer at the Paris Observatory. In 1959, American astronomer Merle F. Walker invited Lallemand and Duchesne to install their electronic camera at the focus of the 120-in. reflector at the Lick Observatory. There, the trio first measured the differential rotation of the nucleus of M31 (the Andromeda Galaxy).

Many variations of this detector were constructed and utilized at observatories worldwide. In particular, Lallemand developed a wide-field camera with an 8-cm square photocell. Employed on the Canada–France–Hawaii telescope, it provided high-resolution views of the jet seen in the radio galaxy M87. Lallemand was appointed director of the Astrophysical Institute at Paris in 1960. The following year, he was awarded the chair of physical methods of astronomy at the Collège de France.

In the course of his career, Lallemand collected many honors and awards; among them were four prizes of the French Academy of Sciences. Along with his collaborator Duchesne, he received the prize of the French Conseil Supérieur de la Recherche Scientifique (1956). Lallemand was the recipient of the Eddington Medal of the Royal Astronomical Society (1962) and the Paul and Marie Stroobant Prize of the Royal Academy of Belgium (1962). He was made a Commander of the Legion of Honor (1964) and Grand Officer of the National Order of Merit (1968). The universities of Padua and Geneva bestowed honorary doctorates upon him. Lallemand's name is attached to the prize awarded every 2 years to an astronomer by the French Academy of Sciences.

Lallemand was an officer of many important associations and committees. He served as president of the French National Committee on Astronomy (1963–1967), president of the French Society of Physics (1964), and president of the Bureau of Longitudes (1964). He likewise participated in the council to the European Southern

Observatory [ESO] and the management of the Haute-Provence Observatory. Lallemand retired in 1974.

Albert Bijaoui

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Lambert, Johann Heinrich [Jean Henry]

Born **Mülhausen, (Mulhouse, Haut-Rhin), France, 26 August 1728**
Died **Berlin, (Germany), 25 September 1777**

Johann Lambert was a physicist known for pioneering work in photometry and in astronomy for his ideas of the nature of the Milky Way. In physics, Lambert is remembered by the unit for illumination density and a number of laws that bear his name.

Lambert was born the son of Lukas Lambert, a tailor, and Elisabeth Schmerber. The family lived in very modest if not poor conditions. He had to help his father and at the age of 12 was taken out of school to learn the trade. Instead, his younger brother became a tailor, leaving Lambert time for private study of literature, the Latin and French languages, calculus, and elementary sciences. About this time, he became interested in astronomy and started to observe the sky.

Lambert gained employment from the Mulhouse town chronicler named Reber for a modest income, and in 1743 he became a bookkeeper for an ironworks at Seppois. He observed the bright comet C/1743 X1 (Klinkenberg-de Chéseaux) and attempted to calculate its orbit. In 1745, Lambert went to Basle to act as a science writer for professor Johann Rudolf Iselin and to continue his studies in science and philosophy.

In 1748, Lambert accepted a position as teacher in the home of Reichsgraf Peter von Salis, in Chur, Switzerland, where he stayed for 8 years. During this time he undertook many investigations that became the foundation of his later scientific and philosophical work, including the 1749 idea of a disk-shaped Milky Way. In 1753, Lambert became a member of the Helvetische Gesellschaft and in 1754 of the Physikalisch–mathematische Gesellschaft in Basle, for which he published his first paper, the results of meteorological observations in 1755.

In 1756, Lambert left Chur to travel through western Europe, together with two students. Their first destination was Göttingen where they made academic contacts: In 1757, Lambert was elected a member of the Göttingingische Sozietät. In the following 2 years, they were based in Utrecht, the Netherlands, and from there visited academics throughout the country. After further journeys to France and Italy, Lambert returned to the Salis family in late 1758.

In May 1759, Lambert visited Zürich, where he worked with Johannes Gessner and published his *Freye Perspektive* (Free perspective). From there he returned to Mülhausen to stay with his mother, sisters, and brothers. When his mother died soon afterward, Lambert moved to Augsburg, where he published some of his most important works: *Photometria* (1760), a foundation of photometry, *Eigenschaften über Kometenbahnen* (1761), a geometrical method to determine cometary orbits, and *Cosmologische Briefe* (1761), a theoretic–philosophical discussion of the Universe and, in particular, the Milky Way.

Lambert was among the scientists who tried to establish a Churbairische Akademie der Wissenschaften. His work at this academy included fundamental theory of cartography. In 1762, because of trouble over the nomination of a professor, Lambert left the academy but remained a correspondent. He returned to Chur where he stayed till autumn 1763 and completed his philosophical work, *Neues Organon*, then traveled *via* Augsburg to Leipzig, where he found a publisher for this work.

In January 1764, Lambert arrived in Berlin. On the recommendation of his Swiss compatriots Sulzer and **Leonhard Euler**, he was introduced to King Frederick II, but it took about a year until the king became convinced of his abilities and made him a member of the Berlin Academy of Sciences in January 1765. At the Berlin Academy, Lambert busily continued his work in philosophy, mathematics, and physical sciences, including astronomy, and published numerous papers. In philosophy, he was a representative of rationalism, and contributed to the theory of knowledge. In mathematics, he worked on the theory of conic sections, trigonometric functions for complex variables (Demoivre's theorem), and hyperbolic functions. In 1765 he found a proof for the irrationality of the numbers π and e.

Lambert continued his meteorological studies and, in 1771, proposed a meteorological world organization. He included the winds in his considerations, and in 1775, published *Hygrometrie*, a treatise of air humidity. In 1774, he founded the *Astronomisches Jahrbuch* together with **Johann Bode**. In 1775, Lambert became ill, but refused medical treatment. Despite increasing health problems, in May 1777 he finally completed his *Pyrometrie*, a treatise of the theory of heat.

In astronomy, Lambert's early observations and calculations on the comet of 1744 led to a geometrical method for their orbital determination (*Eigenschaften über Kometenbahnen*, 1761). He calculated orbits for the comets Messier (C/1769 P1), Lexell (D/1770 L1), and Messier (C/1773 T1). In 1773 he noted that the changes to some cometary orbits differ slightly from what is expected from gravity alone (Lambert's theorem of cometary motion).

In his *Cosmologische Briefe*, Lambert gives a theoretical description of the Universe as it was known at his time. He wished to extend Newtonian physics, well established for the planets, to comets and stellar universe. Moreover, Lambert gives a hierarchical theory of cosmology. Like his contemporaries, he had a "teleological" view of the Universe, assuming *somebody* who defines a *purpose* of everything. Perhaps the most important part of this work, based on his

1749 idea, is the theory of the Milky Way as a disk, a system formed by thousands of stars surrounding the Sun, with the Milky Way plane resembling the "ecliptic for the stars." Lambert thought that every star is a sun with a planetary system. Also, he assumed that there may be other Milky Way systems, potentially forming a higher-order system. When he published his theory in 1761, Lambert was unaware of similar ideas by **Thomas Wright** (1750) and **Immanuel Kant** (1755), of which he learned only after his publication. There are some differences though: Lambert was inconclusive on the nature of the "nebulae," once viewing them as extragalactic stellar systems (as Kant always did), and another time as central bodies for galactic substructures. Also in difference to Kant, Lambert argued for a finite cosmos. But like Kant and Wright, he assumed that all celestial bodies, even the Sun and comets, are inhabited. Lambert's theory of diffuse reflection, developed in *Photometria*, introduced the important term *albedo* for the fraction of diffusely reflected light by surfaces. He also wrote on aurorae, zodiacal light, lunar topography, and the (nonexistent) satellite of Venus. The *Astronomisches Jahrbuch* he founded in 1774 became an important periodical under the direction of Bode. Lambert died unmarried.

Hartmut Frommert

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Lamech, Felix

➔ **Chemla-Lameche, Felix**

Lamont, John [Johann Von]

Born **Corriemulzie near Braemar, (Highland), Scotland, 13 December 1805**
Died **Munich, Germany, 6 August 1879**

John Lamont's principal work was in practical astronomy, chiefly the measurement of the positions of stars, particularly in clusters such as *h* and χ Persei.

Lamont was born of Roman Catholic parents; his father died in 1816. Too poor to obtain advanced schooling at home, at the age of 12 Lamont was given a scholarship to attend a Benedictine monastery college at Ratisbon, Bavaria. He did so, with a view to the priesthood, but abandoned this project and studied astronomy at Munich.

Lamont joined the staff (assistant astronomer) of the Royal Observatory at Bogenhausen (Munich Observatory) in 1830, and was appointed director in 1835. He succeeded **Johann Soldner**. (This post was equal to that of Astronomer Royal for Bavaria; later he became professor of astronomy at Munich University.)

Lamont now controlled the second largest refracting telescope in existence. On at least two occasions he made prediscovery observations of Neptune, though did not recognize it as a planet. Lamont's orbital calculations for Saturn's and Uranus's satellites resulted in masses for those two planets. He also observed comet 1P/Halley in 1836.

In astrophysics, Lamont made early sketches of stellar spectra (1838). In geophysics, for which he is most famous, Lamont made the 1850 discovery of the Earth's 11-year magnetic period.

Lamont was a member of the English Royal Society and the Royal Astronomical Society. He never married, and after his death, he left his money and property to establish scholarships for young students of science.

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Lampland, Carl Otto

Born **near Hayfield, Minnesota, USA, 29 December 1873**
Died **Flagstaff, Arizona, USA, 14 December 1951**

Carl Lampland was involved with both of the Solar System projects for which the Lowell Observatory became famous: observations of Mars and the search for "Planet X." He also accumulated a massive collection of fine photographs of nebulae, including galaxies and gaseous nebulae, and made accurate estimates of the temperatures and temperature balances for various objects in the Solar System.

Lampland was the third of 11 children born to Norwegian parents. He received a B.S. degree in 1899 from Valparaiso Normal School at Valparaiso, Indiana. Lampland then graduated with a B.A. degree in astronomy from Indiana University in 1902. He accepted a position as astronomer at the invitation of **Percival Lowell** from the Lowell Observatory in 1902. Lampland also received an M.A. degree in 1906 and an honorary L.L.D. in 1930 from Indiana University.

In the early years at Flagstaff, Lampland was closely associated with Lowell in observing the planets, particularly Mars. He designed the planetary cameras used on the 24-in. Clark refractor, for which he received the medal of the Royal Photographical Society of Great Britain. In 1905, Lampland initiated the first photographic search for the trans-Neptunian planet postulated by Lowell. After Lowell added a 42-in. reflector to the observatory's telescopes in 1909, Lampland served as the principal observer with that instrument for the next 42 years. With it, he made over 10,000 photographs of nebulae, star clusters, variable stars, novae, and planets. He studied these photographs and published interpretations of the changes they revealed. For example, Lampland conducted an extensive campaign to record changes in NGC 2261, after changes in that nebula were noted by **John Mellish** and documented by **Edwin Hubble**. Lampland was responsible for the recognition of the second truly variable nebular phenomenon, the expansion of the Crab Nebula supernova remnant, showing that it must have formed about the time of the 1054 supernova. Unfortunately, Lampland was extremely reluctant to publish the results of his photographic work, so much so that in 1948 the International Astronomical Union passed a resolution pointing out the desirability of having the photographs published. Sadly, he died within a few years after the resolution added importance to his work; thousands of his excellent photographs remain unpublished.

In collaboration with **William Coblentz** of the National Bureau of Standards, Lampland measured the temperatures of the planets with thermocouples that he constructed. Based on those measurements, and in collaboration with **Donald Menzel**, they concluded that the energy reflected, and reradiated, from the planets was very nearly that which each planet received from the Sun.

Lampland was a member of several professional societies, including the American Academy of Arts and Sciences. He married Verna B. Darby, a classmate from Indiana University, in 1911. She frequently worked with him as an assistant on the 42-in. telescope.

Henry L. Giclas

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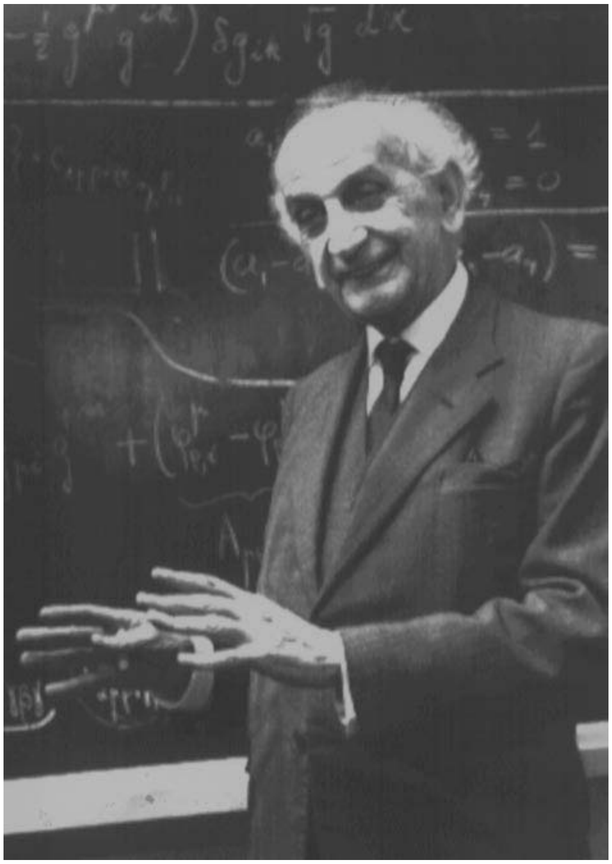
Lanczos, Cornelius

Born **Székesfehérvár, (Hungary), 2 February 1893**
Died **Budapest, Hungary, 25 June 1974**

Hungarian mathematical physicist Cornelius Lanczos explored some of the consequences of **Albert Einstein**'s general theory of relativity pertinent to cosmology, for instance, how the variables expressing measurable quantities must connect across discontinuities in curved space.

Born Kornel Löwy in Hungary, Lanczos changed his name to conceal his German origins. His father, Carolus Löwy, a lawyer, provided for his broad education. He attended a Jewish elementary school, learning several foreign languages, and the local gymnasium, run by the Catholic Cistercians. Graduating from the Gymnasium in 1910, Lanczos entered the University of Budapest in the fall of that year. His teachers in physics, Loránd (Roland) Eötvös, and in mathematics, Lipot (Leopold) Fejér, inspired him to excel in these fields.



Upon graduation in 1915, Lanczos received an appointment as assistant at the Technical University of Budapest, where he worked on relativity theory, dedicating his dissertation, with permission, to Einstein. After receiving his doctorate in 1921, he left Hungary because of its increasing hostility to Jews, and took a position as assistant to the physicist Franz Himstadt at the University of Freiburg in Germany.

In 1924 Lanczos moved to Frankfurt am Main, becoming a colleague of Paul Epstein. During 1928/1929 he was Einstein's assistant in Berlin, returning to Frankfurt at the end of that year. During the 1920s Lanczos joined the German Physical Society and published papers on the general theory of relativity, on a simplified coordinate system for Einstein's gravitation equations, on the expected red shift in a De Sitter universe, and on cosmology. In this period he independently discovered the mathematical equivalence of Werner Heisenberg's discrete matrix representation and **Erwin Schrödinger**'s continuous wave representation of the formal expressions of quantum mechanics expressible as integral equations.

In 1931 Lanczos spent a year as visiting professor at Purdue University in Lafayette, Indiana, USA, returning briefly to Germany during 1932. Recognizing that overt discrimination made continued work there impossible for a person of Jewish origins, he returned to Purdue as a professor that same year. Lanczos' work focused on mathematical physics and numerical analysis, and he had an extensive correspondence with Einstein. Extending his interest in relativity, he published several fundamental papers in this area.

During 1944 Lanczos took a position at Boeing Aircraft Company where he worked on applications of mathematics to aircraft design, developing numerical methods to solve certain problems. He resigned his position at Purdue in 1946 to take a permanent position at Boeing, but in 1949 he moved to the Institute for Numerical Analysis of the National Bureau of Standards in Los Angeles, California, working on digital computers and numerical methods.

For political reasons connected with the investigations of Joseph R. McCarthy in the United States Senate, Lanczos became uncomfortable in the USA, and was delighted to receive an offer from Schrödinger to head the Theoretical Physics Department at the Dublin Institute for Advanced Study in Ireland, which post he accepted in 1952. (He also held visiting professorships at North Carolina State University, Raleigh, North Carolina, USA, and received the Chauvenet prize of the mathematical Association of America during the 1960s.) At the Dublin Institute, Lanczos happily returned to science and over the next few years he published more than a hundred papers on topics primarily related to the theory of relativity. Late in life he returned to Hungary.

Katherine Haramundanis

Alternate name

Löwy Kornel

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Landgrave of Hessen-Kassel

➲ **Wilhelm IV**

Lane, Jonathan Homer

Born **Genesee, New York, USA, 9 August 1819**
Died **Washington, District of Columbia, USA, 3 May 1880**

Mathematical physicist J. Homer Lane produced the earliest theoretical treatment of the Sun's internal structure (1870) by applying known physical laws to the behavior of a gaseous sphere (under certain assumptions). Lane's solar studies were well informed by contemporary research in thermodynamics and represented an outgrowth of his laboratory investigations into the behavior of gases at very low temperatures.

Lane was the son of farmers Mark and Henrietta (*née* Tenny) Lane. First educated at home, Lane was admitted to Phillips Academy, Exeter, New Hampshire in 1839, where he developed a lifelong preoccupation with the determination of absolute zero, the theoretically lowest possible temperature. Lane then entered Yale College as a sophomore from which he graduated in 1846. There, he was influenced by the astronomical and meteorological research of **Denison Olmsted**.

After teaching for one year and working briefly for the United States Coast Survey, Lane obtained a position in 1848 as assistant examiner at the United States Patent Office in Washington, DC. He was promoted to principal examiner in 1851. Through his position, Lane became acquainted with the nation's leading physical scientists and astronomers, including **Joseph Henry**, **Simon Newcomb**, and **Benjamin Peirce**. Through their encouragement and occasional support, Lane pursued the construction of his "cold apparatus" for reducing gases to very low temperatures. Although these experiments were judged to be generally successful, Lane never published an account of his cryogenic investigations. He never married.

A change of administration forced Lane out of the Patent Office in 1857, and for the next decade or so, he pursued research at the home of his brother in rural Franklin, Pennsylvania. After the Civil War, Lane returned to Washington (1866), resumed his experiments on gases, and turned his thoughts toward an understanding of the Sun's temperature, density, and pressure. In 1869, he obtained a position at the Office of Weights and Measures, forerunner of the National Bureau of Standards, where he remained for the rest of his life.

In 1869, Lane delivered a paper, "On the Theoretical Temperature of the Sun," before the National Academy of Sciences. It was published the following year in the *American Journal of Science*. Lane was the first to derive a mathematical relation between the temperature, pressure, and density of a gaseous sphere, under the assumed conditions of hydrostatic equilibrium and thermal or convective equilibrium. These yielded a single differential equation that Lane solved for the surface temperature of the Sun (under an assumed range of specific heats). Had he carried the analysis further, Lane might also have calculated the central temperature of the Sun. Implicit in Lane's results was his recognition that the internal temperature would vary inversely with the radius of the sphere. This mathematical relationship, later dubbed Lane's law (or more properly the Lane–Emden equation), was not demonstrated explicitly until 1887 by **William Thomson** (Lord Kelvin). Independently of Lane, **Georg Ritter** derived the same mathematical equations in a series of papers published between 1878 and 1883.

Lane's paper garnered him election to the National Academy of Sciences in 1872. But in spite of this recognition, Lane remained an astronomical outsider. He did not pay attention to the rapidly emerging field of observational astrophysics, and the spectacular findings derived from spectroscopic studies of the Sun. His contribution is viewed not as a remarkable fluke, but instead as the successful application of known physical laws to the construction of a theoretical model of the Sun (and other stars), whose fuller development awaited the next generation of astronomers and physicists.

Jordan D. Marché, II

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Langley, Samuel Pierpont

Born **Roxbury, Massachusetts, USA, 22 August 1834**
Died **Aiken, South Carolina, USA, 27 February 1906**

Samuel Langley was a pioneer solar astrophysicist and founder of the Smithsonian Astrophysical Observatory. He was the son of Samuel Langley, a Boston wholesale merchant, and Mary Sumner Williams. He was a descendent of the prominent Mather family. Langley was educated in several private schools, the Boston Latin School, and the Boston High School, from which he graduated in 1851. He never married. In his youth Langley used his father's small telescope; at 20, he and his only brother John started building small telescopes.

With few employment opportunities in astronomy, Langley aimed to become an architect or civil engineer. Instead of attending college, he decided to go to work immediately to learn these crafts, working some time in a Boston architectural firm; he obtained similar work in Saint Louis, Missouri, then in Chicago, Illinois. Through this experience, Langley developed superb mechanical and freehand drawing skills, as well as learning sound business procedures. But he became disinterested in architecture and returned home in 1864. His brother had just been discharged from the Union Navy, after 3 years in the Civil War. In 1865, the Langley brothers toured the centers of culture and learning in Europe; this included many of Europe's observatories. On his return, Langley learned that Harvard College Observatory was expanding. Impressed with Langley's enthusiasm and experience in telescope construction, professor **Joseph Winlock** hired him as an observatory assistant. He remained at Harvard College Observatory less than a year. In 1866, Langley was offered the professorship of mathematics at the United States Naval Academy with the understanding that his primary duty would be to restore their small astronomical observatory; it had been unused while the Naval Academy spent the Civil War in Newport, Rhode Island.

At the invitation of Western University of Pennsylvania (later Pittsburgh) trustee William Thaw, Langley agreed to take charge of the newly acquired Allegheny Observatory as professor of astronomy and physics in 1867. Thaw and two other wealthy Pennsylvanians had conceived the observatory in 1859, shortly after the appearance of comet C/1858 L1 (Donati). The observatory opened on 27 November 1861 with a 13-in. Fitz refractor telescope, then the third largest in the world. In the first years, it was used strictly for the entertainment of the members of the Allegheny Telescope Association. As interest waned, the observatory went into debt. In May 1867, the club donated the observatory to the university.

Langley developed what he termed the New Astronomy, which concentrated on measuring the celestial bodies and analyzing their physical composition, structure, and other properties. This later developed into astrophysics. His greatest astrophysical achievement was measuring the distribution of heat in the spectrum of the Sun. Given the lack of precision of instruments, he invented the bolometer in December of 1880, used to measure the amount of radiation coming from celestial bodies with very great accuracy. It electrically measures a slight difference in resistance between two thin, blackened strips of tape, when one strip receives radiation while the other does not; the difference indicates the amount of radiation received.

Langley spent years studying the selective absorption of solar radiation by the Earth's atmosphere. Up until 1881, this study had been limited to the relatively low altitudes of Pennsylvania. With funding from Thaw and the United States Army Signal Service (responsible for much of the weather forecasting of that era), Langley led an expedition to Mount Whitney (14,494 ft.). The result was a 240-page technical report, "Researches on Solar Heat and Its Absorption by the Earth's Atmosphere: A Report on the Mount Whitney Expedition," published in 1884.

Using these data, Langley attempted to measure the solar constant, the quantity of solar radiation striking the top of the Earth's atmosphere. He judged it to be 3 cal cm^{-2} min^{-1}. Unfortunately, Langley miscalculated the absorption of the Sun's energy by the air. Although the reductions of his own data were in error, this value of the solar constant was accepted by scientists for about 20 years, thanks to his reputation.

During the Mount Whitney expedition, Langley discovered a previously unobserved extension of the infrared region of the spectrum. At the Allegheny Observatory, he was able to start mapping this new region of the spectrum. He also used the bolometer to obtain a good approximation of the temperature of the Moon.

Langley observed several solar eclipses to study the Sun's corona. His classic 1873 illustration of a sunspot became standard in textbooks of the time.

As a science popularizer, Langley contributed occasional items to the *Pittsburgh Gazette* and lectured throughout the Pittsburgh area.

To help fund his research, Langley found a way that the Allegheny Observatory could generate revenue by selling accurate time. In 1869, he obtained a transit telescope to determine the exact time by the stars, and he assembled a special telegraph system connected to his master clock. Langley solved the problems of the railroads by creating his own precise time, known as the Allegheny system, which he transmitted to the railroads, twice daily, over the telegraph. Although he had originally designed the system to provide time to the city clocks of Allegheny City and Pittsburgh, his railroad customers became much more important. Within the first 4 years, the time service brought in $60,000, which helped pay for the observatory's research and the purchase of instruments. Originally, the university's trustees had thought that Langley's $2,000 a year salary would be the observatory's largest expense. Langley's time service also inspired the eventual time zone system we have today. With the Allegheny system as an example, Charles Ferdinand Dowd and Sandford Fleming started lobbying and promoting a time zone system. Consequently, the great railroad conference of 1883 set up four American time zones; this idea was accepted internationally in 1884.

Langley was appointed assistant secretary of the Smithsonian Institution on 12 January 1887. After naturalist Spencer F. Baird died later that year, Langley succeeded him as the third secretary of the institution on 18 November. This was the most powerful scientific position in America. Until 1891, Langley continued his solar and aerodynamic research half the time at Allegheny until **James Keeler** became director there. In the spring of 1890 he founded the Smithsonian Astrophysical Observatory. Supported only minimally by Congress, the observatory lacked sufficient facilities for many years, but Langley was able to turn it into a valuable research facility.

Langley is also an important pioneer of flight and scientific research into aerodynamics. His greatest successes came in 1896, when two "aerodromes" were catapulted from a houseboat on the Potomac River for flights of 3,000 ft. and 4,200 ft. Although both were unmanned vehicles, they were the first sustained free flights of power-propelled heavier-than-air machines.

Langley was president of the American Association for the Advancement of Science (1888), a member of the National Academy of Science, fellow of the Royal Society of London and the Royal Society of Edinburgh, and awarded a Draper Medal, a Rumford Medal, and a Janssen Medal. He received honorary degrees from Oxford, Cambridge, Harvard, Princeton, Michigan, and Wisconsin universities. The international unit of radiant energy was named the langley, in 1947.

Glenn A. Walsh

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Langren, Michael Florent van

Born **Amsterdam, the Netherlands or Mechlin or Antwerp, (Belgium), *circa* 1600**
Died **Brussels, (Belgium), May 1675**

Michael van Langren was active in cartography, navigation, and engineering, but his principal significance for the history of astronomy is in his mapping of the lunar surface. Not only were his maps as good as or better than those of his contemporaries **Giovanni Riccioli** and **Johannes Hevel**, but his nomenclature for lunar features also established the pattern that is still followed today. He also published a treatise on the comet of 1652 (C/1652 Y1).

Langren's mother and father (Arnold Florent, also a cartographer) were Catholics and immigrated to Brussels, then under Spanish rule. The patronage of Catholic rulers, or the quest for it, was an important factor in Langren's career.

By 1625, Langren was attempting to solve the problem of longitude determination at sea by using the Moon as a universal time finder. Equipped with an ephemeris predicting the times of appearances and disappearances (at sunrises and sunsets in the waxing and waning moon respectively) of lunar features, a navigator could, in principle, know the time at the longitude of the ephemeris by observing the events themselves. Comparing the predicted time with local time would yield the longitude difference. Such a system required detailed and accurate maps of the Moon at each phase using a coherent coordinate system and libration theory.

Langren had plans to create this apparatus by the early 1630s, but the death of his prospective Spanish patroness, Princess Isabella, delayed the appearance of his first manuscript map of the Moon until early 1645. After receiving a privilege in Brussels for his lunar map, he printed his own engraving of it entitled *Plenilunii Lumina Austriaca Philippica* shortly after March 1645. This map, as the title indicates, was of the Full Moon; the entire series of phases, though drafted in manuscript, was never published.

Langren's map of the Full Moon introduced a rich nomenclature for lunar features. His scheme named prominent craters and mountains after illustrious scientists and rulers. He identified seemingly aquatic features with standard Latin terms such as *mare, sinus, oceanus, lacus, flumen* (sea, bay, ocean, lake, river), and others. His terms for highlands were also Latin and included *terra*, *littus*, *promontorium*, and *montes* (land, shore, cape, and mountain range). Most of the specific names Langren assigned have been changed, but his general scheme is recognizable today, and the crater he named Langrenus still bears that name.

James M. Lattis

Alternate name

Langrenus

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Langrenus

➤ **Langren, Michael Florent van**

Lansbergen, Jacob

Born **Goes, The Netherlands, 1590**
Died **Middelburg, The Netherlands, 1657**

Physician Jacob Lansbergen was important in the Copernican debate within the Low Countries. His *Apologia* (1663) defended the author's late father, Copernican **Philip Lansbergen**, against polemical attacks from anti-Copernicans **Libertus Fromondus** and **Marin Mersenne**.

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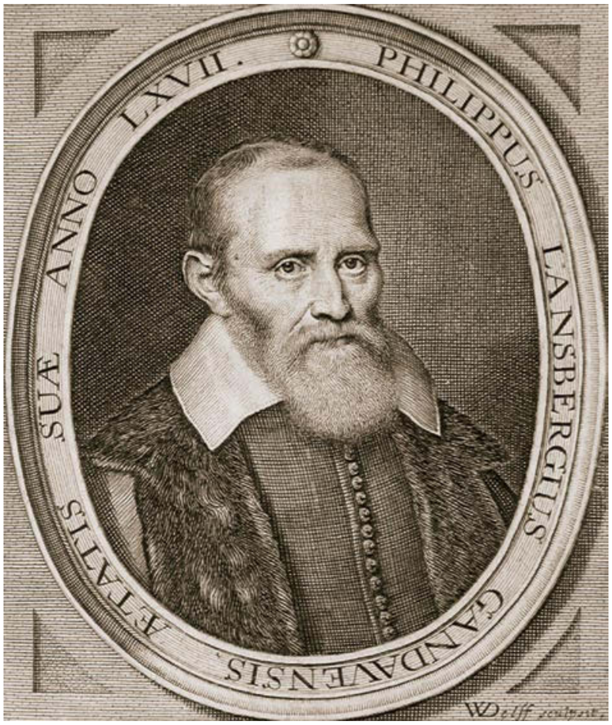
Lansbergen, Philip

Born **Ghent, (Belgium), 25 August 1561**
Died **Middelburg, The Netherlands, 8 December 1632**

Philip Lansbergen was an early advocate of a moving Earth and Sun-centered system.

Born of Protestant parents who left the Netherlands for religious reasons in 1566, young Philip Lansbergen grew up in France and England, where he was educated in mathematics and theology. Upon his return to the Netherlands without a degree in 1579, he accepted employment as a minister in Antwerp, but when this city was conquered by the Spanish in 1585, Lansbergen went to Leiden to apply himself to theology. Shortly after he married Sara Lievaerts in 1586, Lansbergen moved to Goes to be a minister again. Here, alongside his religious acts, he developed his liberal views on astronomy, was engaged in politics, and practiced medicine.



In 1613, after a series of minor incidents, Lansbergen ran into serious problems. The death of one of his patients caused a protracted medical controversy, and his opposition to the appointment of a new mayor ended in his dismissal. Thereupon, he moved to Middelburg and, provided with an annuity of "the Staten van Zeeland," Lansbergen addressed himself mainly to astronomy, mathematics, and medicine until his death in 1632. His wife died in 1625; he left six sons and four daughters.

A follower of **Nicolaus Copernicus**, Lansbergen spoke out for a moving Earth in his writings. Especially his *De motus solis* (1619) and *Bedenckinghen op den daghelijckschen ende jaerlijckschen loop vanden aerdt-cloot* (1629) presented further proof supporting Copernicus's system. However, although being modern-minded on astronomy, he refused to accept **Johannes Kepler**'s theory on the elliptical motion of the planets. Sharp attacks and fierce criticism of Kepler by Lansbergen culminated in the publication of his own astronomical tables based on circular planetary motion instead. Lansbergen thought these *Tabulae motuum coelestium perpetuae* (1632) could rival Kepler's *Tabulae Rudolphinae* (1627). Initially these tables found a ready market, but interest soon waned when their accuracy proved to be not comparable to those of Kepler.

Lansbergen's further works on astronomy and mathematics comprised studies on the use of the astronomical quadrant and astrolabe, the sizes and distances of celestial bodies, the design of planar sundials, and problems in spherical trigonometry. In the Netherlands Lansbergen was one of the first to defend openly Copernicus's theory, and for a long time he was the sole Dutch theologian holding his notion of a moving Earth.

Steven M. van Roode

Alternate name

Van Lansbergen, Philip

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Laplace, Pierre-Simon de

Born **Beaumont-en-Auge, (Calvados), France, 23 March 1749**
Died **Paris, France, 5 March 1827**

Pierre-Simon de Laplace developed numerous mathematical techniques, played an important role in the development of the metric system, and made significant contributions to celestial mechanics. His name is remembered in the Kant–Laplace hypothesis for the origin of the Solar System and is a mathematical operator called the Laplacian. His father, Pierre, was a cider merchant, and his mother Marie-Anne Sochon came from a landowning family; he had a sister, Marie-Anne, born in 1745. Laplace married Marie Charlotte de Courty de Romanges on 15 May 1788. They had a daughter, Sophie-Suzanne, who died giving birth to a daughter, and a son, Charles-Émile, who died in 1874.

His father expected Laplace to make a career in the Church, so he entered the local Benedictine school; at 16, he entered the College of Arts at Caen, a Jesuit school, still intending to study theology, but his interest in mathematics was piqued by two of his teachers, Christopher Gadbled and Pierre le Canu.

Le Canu was acquainted with **Jean d'Alembert**; when Laplace left the College of Arts without taking his degree, he went to Paris with a letter of recommendation from le Canu. According to legend, d'Alembert sent Laplace away after giving him some mathematical problems, which Laplace solved overnight. In the event, d'Alembert became one of Laplace's great supporters, and obtained for him a position at the Military School in Paris.

The position meant Laplace could afford to stay in Paris, and he began to bombard the *Académie royale des sciences* with papers, the first one presented on 28 March 1770. Within 2 years, he presented 13 papers to the *academy*, of which four were eventually published.

Laplace's brilliance was clear to everyone, including himself. In 1771 and 1772, the *academy* elected to membership two scientists, older but less capable. Laplace threatened to leave Paris; d'Alembert wrote to **Joseph Lagrange**, asking on Laplace's behalf if there were any positions available at the Academy of Sciences in Berlin. In the end, Laplace was elected to membership in the *academy* on 1 January 1773, and stayed in Paris.

Laplace developed many important mathematical techniques that informed probability theory, physical science (especially the analysis of heat and sound), cosmology, and celestial mechanics. He was able at last to provide an answer to a query raised by **Isaac Newton** in his *Opticks* about the long-term stability of the planetary orbits. The mutual gravitation of the planets causes their five orbital parameters to vary; finding the exact nature of these variations (called inequalities) was an important part of celestial mechanics in the years following the triumph of Newton. There are two types of variation: first, a periodic variation, whereby an orbital parameter stays close to or oscillates about a mean value, and second, a secular variation, whereby an orbital parameter increases (or decreases) without bound. Determination of the periodic or secular nature of a planet's semimajor axis *a*, eccentricity *e*, or orbital inclination *i* would shed light on the long-term stability of the Solar System.

On 10 February 1773, only a month after his election to the academy, Laplace read the first part of a paper on the secular inequalities of the planets; the second part, probably read before 27 April 1774, examined the secular variations of the semimajor axis, and through a variety of *ad hoc* methods, Laplace claimed to show that the variations were purely periodic. Shortly afterward, Lagrange submitted a paper concerning variations in the line of nodes and the orbital inclination, showing that the latter were periodic, not secular. Lagrange's paper was given to Laplace to referee. Laplace immediately applied Lagrange's method, analyzed the eccentricity and (in modern parlance) the argument of perihelion, and showed that the variations of the eccentricity were likewise periodic. Laplace presented his own work in several parts between 14 July 1773 and 17 December 1774, and managed to include his work in the *Mémoirs* of the academy for 1772, all *before* Lagrange's paper appeared. In 1776, Lagrange demonstrated that the semimajor axes of the planets underwent only periodic variations. Thus Lagrange and Laplace showed that orbital parameters remain bounded, though they still needed to establish that the variations were not only periodic but also small. In 1784, Laplace provided that result.

Today, credit is often given to Laplace alone as having proven the long-term stability of the Solar System. This stems in no small part from Laplace's popular publications, beginning with *Exposition du système du monde* (1796), a popular account of celestial mechanics. In it, Laplace presented the nebular hypothesis of the origin of the Solar System. Laplace noted five key observations about the Solar System:

(1) planets orbit the Sun in the same direction and in roughly the same plane;
(2) planetary satellites likewise revolve around their primaries in the same direction and in the same plane;
(3) planets, satellites, and the Sun all rotate about their own axes in the same direction and in roughly the same plane (or so Laplace thought, though today we know it to be untrue);
(4) orbital eccentricities of planets and satellites are very small; and
(5) comets disobey all of the above, and appear to have their orbits randomly distributed.

Laplace noted that the only person to put forward an origin of the Solar System since the discoveries of Newton was **Georges Leclerc**, who had suggested that a cometary collision with the Sun yielded parts that later coalesced to form the planets. Laplace offered a new hypothesis: The Solar System began as a vast cloud, which began to collapse under its own gravitation, with portions of the cloud condensing into planets and their satellites. Laplace pointed to the Pleiades as examples of a case where a cloud might condense into a multiple star system. Although the nebular hypothesis as Laplace presented it is no longer considered valid, the current theory of the formation of the Solar System incorporates many of Laplace's ideas.

Système du monde was a mere prelude to a more ambitious and more mathematical work, *Mécanique céleste*, in which Laplace summarized everything known about celestial mechanics in five dense volumes. The work provided the first fully analytical solution to calculations of the orbital elements for a celestial body from three observations. The technique assumed that the second (middle) observation was exact, and that the first and third observations were to be approximated (*via* truncated series expansion) to a high degree of accuracy.

Laplace sent *Mécanique céleste*'s first two volumes, which appeared in 1799, to a rising star of French politics, Napoleon Bonaparte. Napoleon had been a student at the Military School, and in September 1785 Laplace had tested Napoleon in mathematics. Napoleon installed Laplace, though only briefly, as Minister of the Interior (1799), and later made him a Grand Officer of the Legion of Honor (1802), a Chancellor of the Senate (1803), and a Count of the Empire (1806). Laplace actively participated in the Institut de France, the *École Polytechnique,* and the *Bureau des longitudes*.

Jeff Suzuki

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Lārī: Muṣliḥ al-Dīn Muḥammad ibn Ṣalāḥ ibn Jalāl al-Sàdī al-ˀIbādī al-Anṣārī al-Lārī

Born **Lār, (Iran), *circa* 1510**
Died **Āmid, Diyārbakr, (Turkey), 1572**

Muṣliḥ al-Dīn al-Lārī was an eagerly sought after scholar and teacher who worked and wrote in the fields of logic, mathematics, astronomy, law, Qur'ān-exegesis (*tafsīr*), and rational theology (*kalām*). He was born in the south-Iranian city of Lār and studied with Ghiyāth al-Dīn al-Shīrāzī (died: 1542), a scholar with profound interests in astronomy. Ghiyāth al-Dīn wrote, among other things, a commentary on the *Almagest* and a commentary on the astronomical handbook by **Ulugh Beg** and his collaborators. The first commentary claims to complete **Ptolemy**'s book, while the second maintains that it will deliver keys to the astronomers (for carrying out their profession). Thus, it may well be that Lārī studied these works as well as the entire scope of problems dealt with by *ˁilm al-hay'a* (astronomy) with Shīrāzī. From Iran, Lārī moved to India and worked some time between 1530 and 1556 at the Moghul court of Humāyūn (1508–1556). In 1556 he traveled to the Ottoman Empire, first to Aleppo, then to Istanbul, and finally to Diyārbakr. In Diyārbakr, Lārī worked for Governor Iskandar Pasha. In 1559, he was appointed head teacher at the Hüsrev Pasha school in Diyārbakr and the city's Muftī (a type of legal magistrate).

One mathematical work and three astronomical treatises are known to be extant today. The mathematical work discusses geometrical problems. The astronomical treatises are: a commentary, dedicated to Humāyūn, on **ˁAlī Qūshjī**'s introductory Persian text on astronomy, a text on dawn and twilight, and an astronomical treatise composed in the form of questions and answers. His most influential astronomical text, judged on the basis of the extant copies, was his commentary on Qūshjī's introductory text. Except for this work, none of Lārī's astronomical and mathematical writings have been studied so far.

Sonja Brentjes

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Larmor, Joseph

Born **Magheragall, Co. Antrim, (Northern Ireland), 11 July 1857**
Died **Holywood, Co. Down, Northern Ireland, 19 May 1942**

Irish mathematician and theoretical physicist Joseph Larmor gave his name to the Larmor radius, frequency, and precession, which describe the motion of a charged particle in a magnetic field. He calculated these with special reference to the behavior of a low-mass, negatively charged particle called the electron, which he was the first to predict.

Larmor was born to Hugh Larmor, a farmer, and Anna Wright Larmor. He was named after his maternal grandfather and was the eldest child of a large family. Hugh Larmor gave up farming when Joseph was around six or seven to become a grocer and moved the family to Belfast, where Joseph attended the Royal Belfast Academical Institution. Upon completion of his schooling at the Institution, Larmor entered Queen's College, Belfast, where he received his BA and MA. Upon graduation in 1877 he went to Saint John's College, Cambridge, to study for the mathematical *tripos* there. Larmor lost a year due to illness, but returned with a vengeance. He was senior wrangler (first place in the *tripos* examinations) in 1880 – second place that year was J. J. Thomson – and won the Smith Prize.

Upon graduation Larmor was appointed a fellow of Saint John's College and promptly returned to Ireland to become professor of natural philosophy at Queen's College, Galway. In 1884 he became a member of the London Mathematical Society, serving as a council member from 1887 to 1912, president in 1890 and 1891, and treasurer from 1892 to 1914. Larmor remained at Galway for 5 years before returning to Saint John's as a lecturer in 1885. He was elected a fellow of the Royal Society in 1892 and served as its secretary from 1901 to 1912. In 1898, a lengthy compilation of three of Larmor's papers, later published as *Æther and Matter*, won the Adams Prize at Cambridge. In 1903, with the death of Sir **George Stokes**, he was appointed the Lucasian Professor of Mathematics at Cambridge, a post once held by **Isaac Newton** and currently held by Stephen Hawking.

In 1909 Larmor was knighted and served as a Member of Parliament for the University of Cambridge from 1911 to 1922. He made his first speech in 1912 defending the Unionists in a debate on Irish home rule, though his primary focus in Parliament was to support universities and education in general. Irrespective of the side Larmor took in the Irish debate, he always held the *Emerald Isle* dear to his heart, and he usually spent part of his long vacation there each year.

In 1915 the Royal Society awarded Larmor the Royal Medal, and then in 1921 the Copley Medal. He served on the council of Saint John's College for many years.

Larmor retired from the Lucasian chair in 1932, to be succeeded by **Paul Dirac**, but remained in Cambridge for another year or two before returning to Ireland, retiring at Holywood, County Down, near Belfast, his health deteriorating. Except for one brief return visit to Cambridge, he remained in Ireland. Larmor was a bachelor throughout his life.

Larmor's most significant contribution was the publication of his opus, *Æther and Matter*, in 1900. The work was actually a compilation, with slight revisions, of three important papers he wrote between 1894 and 1897 and published in the *Philosophical Transactions of the Royal Society* on the theory of the electron – the first such prediction of the particle. The work gained support when J. J. Thomson actually discovered the electron in 1897.

This, as with nearly all of his work, built upon Larmor's very first paper that dealt with the Principle of Least Action. **Arthur Eddington** viewed his enthusiasm for this principle as nearly mystical. Larmor's refusal to accept general relativity only waned when he began to see it in terms of the principle of least action.

Æther and Matter brought to a resounding end the plethora of material and mechanical models of the ether. But it did contain the bulk of Larmor's work on the development of the electron. It also contained experimental facts regarding the Lorentz transformation, and at times some authors have suggested the name be changed to the Larmor–Lorentz transformation. As we know, relativity sprang from this transformation, which is ironic considering Larmor's long disbelief in relativity.

In 1897, Larmor showed that the motion of ions in a molecule under the influence of a magnetic field was equivalent to the rotation of the group with an angular velocity about the axis of the field. This effect is now known as Larmor precession.

Larmor also contributed some direct astronomical and geophysical papers. Some of these topics included the correction of the period of the Eulerian nutation for the elasticity of the Earth, a correction for the fluidity of the ocean, a study of the problem of the variation of latitude, a study of the electrical conductivity in the upper atmosphere, and an analysis of sunspot frequencies.

Ian T. Durham

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Lassell, William

Born **Moor Lane, Bolton, (Greater Manchester), England, 18 June 1799**
Died **Maidenhead, Berkshire, England, 5 October 1880**

William Lassell constructed the first large equatorially mounted reflecting telescopes and proved both the viability and the utility of such large instruments. Using his large reflectors, Lassell discovered several satellites of the outer planets.

The son of Nathaniel Lassell, a timber merchant and Hannah (*née* Gregson) Lassell, William was raised in middle-class comfort in a distinctly commercial extended family. He began his education at an elementary school in Bolton and then, at the age of about nine, he entered an academy in Rochdale, Lancashire where Lassell remained for one and a half years. His father died in 1810 while he was still attending school. He started an apprenticeship as a commercial trader in 1814, and by about 1825 he had established himself as a partner in a Liverpool brewing business. Soon afterward, in 1827, he married Maria King of Toxteth.

Lassell was a reluctant, but nonetheless successful businessman spending his leisure hours in the study of astronomy and in developing his mirror-making skills, fashioning excellent mirrors from speculum metal, a difficult material with which to work, for all his telescopes. He had a flair for innovation. Lassell built two 7-in. reflecting telescopes in 1820, one Newtonian and the other Gregorian and commenced astronomical observations in 1821 using the 7-in. Gregorian. In 1836 he advised the Liverpool borough to build an observatory, which eventually came into operation in 1844. In the summer of 1840, Lassell established his own private observatory, Starfield, at West Derby in Liverpool.

Lassell was one of the first English astronomers to abandon the unwieldy altazimuth structures of the **William Herschel** era, constructing a 9-in. Newtonian reflector and installing it at Starfield in 1833 on an equatorial mounting of his own design. By then, Lassell was well established as an amateur astronomer and welcomed other Liverpool amateurs to his new observatory. One frequent visitor was **William R. Dawes** of Ormskirk. Dawes valued the opportunity to observe with Lassell's fine equatorial reflector and shared with the latter his fine library in Ormskirk on reciprocal visits as they formed a long-standing friendship. Lassell was present at Ormskirk when Dawes discovered Saturn's crepe ring.

In 1844, Lassell began contemplating the construction of a 24-in. aperture equatorial reflector. He traveled to Birr Castle in central Ireland to view **William Parsons**'s (Lord Rosse) mirror-making facilities. Hand polishing of so large a speculum-metal mirror following the techniques that Lassell perfected for his 9-in. mirrors would be impractical for the 24-in. mirrors. After several months of trial with a machine built by **James Nasmyth** along similar lines to Lord Rosse's machine, Lassell was not satisfied with the machine's ability. With Nasmyth's assistance, Lassell developed a new mirror-making machine which, by variable epicyclical movements, replicated the motion of the hand in the grinding and polishing processes. Upon completion of the 24-in. telescope in 1845, Lassell used it to discover Neptune's largest satellite, Triton, on 10 October 1846, but he had to wait until late summer of 1847 to obtain full confirmation.

Lassell co-discovered the eighth satellite of Saturn, Hyperion, the discovery date of which was considered by Sir **John Herschel** to have been 19 September 1848, the date of Lassell's second observation of it. **George Bond** and his father **William Bond**, observing at the Harvard College Observatory, independently discovered this satellite very slightly earlier. It was first observed by George on 16 September 1848 and confirmed by both astronomers the following night. Lassell also added to his tally of satellite discoveries in 1851, with the detection of two new satellites of Uranus, Ariel, and Umbriel.

In connection with his observations of Neptune, Lassell at first thought he observed an elongation of the planet's disk, which he interpreted as an indication that Neptune possessed rings similar to those of Saturn. A number of other individuals, including Dawes, testified to the existence of this elongation when viewing Neptune through Lassell's telescope, admittedly the most powerful in England at the time. In fact, **James Challis** and **John Hind** felt that they observed the elongation through other telescopes and at first confirmed Lassell's discovery. Always the skeptical observer, however, Lassell eventually traced the elongation to astigmatism caused by sagging of the 24-in. mirror.

During the 1850s, Lassell devised an improved "astatic" mirror-support system that minimized flexure of the heavy primary mirror, particularly at low altitudes. Following **Thomas Grubb**'s innovative earlier developments in this field, first used in 1835 on the equatorially mounted reflector at Armagh Observatory and later on the much larger reflectors at Birr, this formed the basis of modern mirror-support systems for large reflecting telescopes.

During 1859 and 1860 Lassell constructed an equatorially mounted 48-in. aperture Newtonian reflector at his residence of Bradstones, near Liverpool, where he had moved to avoid increasingly poor observing conditions at Starfield. The new telescope's tube was of a lattice construction to mitigate the formation of differently heated internal air currents, and also to equalize internal and external temperatures more rapidly.

Seeking clearer skies and also possibly enhanced opportunities for making astronomical discoveries, Lassell transported the 48-in. telescope to Valetta, Malta. His tests to delineate the performance of this telescope were published in the *Memoirs of the Royal Astronomical Society* in 1864. The telescope was not installed in a building, but remained in the open air when not in use.

Lassell spent 3 years (late 1861 to 1865) in Malta; he was assisted by **Albert Marth** for 2 of these years. They observed the planets and their satellites and discovered and measured the positions of nearly 600 new nebulae during the years 1863–1865.

In late 1865, Lassell offered the 48-in. telescope to the committee with responsibility for the construction of the Great Melbourne Telescope, but his offer was declined in favor of a proposal from Grubb. After Lassell's return to England from Malta, the 48-in. reflector was not used again and was eventually disposed of as scrap metal.

Although observation of planets and discovery of their satellites are most frequently cited as Lassell's observational interests, it should be noted that he also applied his large telescopes to the study of comets and made an extensive study of the Orion Nebula (M42). These observations were duly reported in various journals of the time. However, Lassell was not inclined to interpretation of his observations. He reported only complete and factual information about what he observed and thus avoided the complications other astronomers frequently encountered with such interpretations. His reported observations stand as exemplars of good observing practice in this regard.

Lassell was one of the most prolific observational astronomers of the 19th century, his results being reported in many issues of the *Memoirs* and *Monthly Notices of the Royal Astronomical Society*. Lassell was awarded an honorary LLD degree from the University of Cambridge. He was elected a fellow of the Royal Astronomical Society on 14 June 1839 and received the Society's Gold Medal in 1849 for the construction of his equatorial telescope and for the discoveries he made with it. He also served as the society's president from 1870 to 1872. Lassell was elected a fellow of the Royal Society in 1849, and was awarded a Royal Medal of the society in 1858. He was also a fellow of the Royal Societies of Edinburgh and Uppsala.

John McFarland

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Lau, Hans Emil

Born **Odense, Denmark, 16 April 1879**
Died **Copenhagen, Denmark, 16 October 1918**

Hans Lau, the son of Peter and Maria Lau, was educated at Copenhagen. He established a private observatory at Horsholm, near Copenhagen, where he investigated double and variable stars and the planets Mars and Jupiter. He also put forward a new theory of Jupiter's constitution.

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Lauchen, Georg Joachim von

❯ **Rheticus**

Laurentius Eichstadius

❯ **Eichstad, Lorenz**

Leadbetter, Charles

Born **Cronton, (Mersey), England, 26 September 1681**
Died **London, England, 21 November 1744**

Charles Leadbetter was one of the first popular English commentators on **Isaac Newton**. Almost nothing is known about his life and work. He taught mathematics, navigation, and astronomy at the *Hand & Pen* in Cock Lane, London, England. Over a period of less than a decade, he published four books in London: *Astronomy, or, The true system of the planets demonstrated: wherein are shewn by instrument, their anomalies, heliocentrick and geocentrick places both in longitude and latitude* (1727), *A compleat system of astronomy …* (1728), *Astronomy of the satellites of the earth, Jupiter and Saturn: grounded upon Sir Isaac Newton's theory of the earth's satellite* (1729), and *Uranoscopia: or, The contemplation of the heavens* (1735).

Robinson M. Yost

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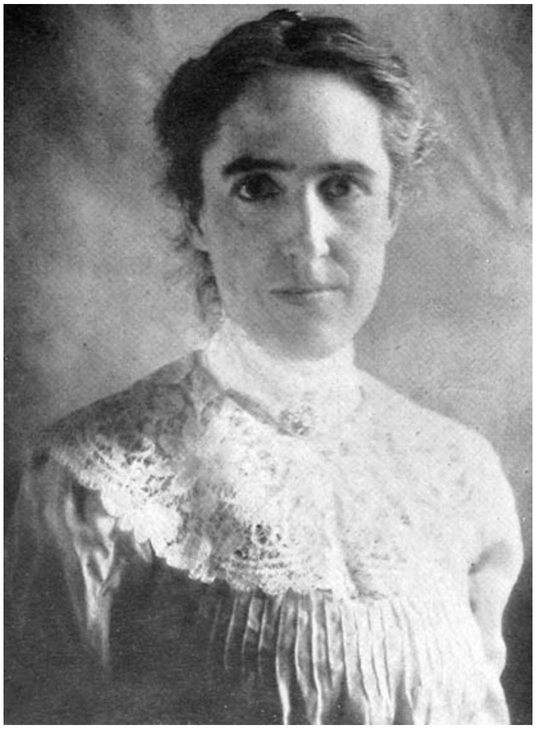
Leavitt, Henrietta Swan

Born **Lancaster, Massachusetts, USA, 4 July 1868**
Died **Cambridge, Massachusetts, USA, 12 December 1921**

American astronomer Henrietta Leavitt discovered the period–luminosity relation. This is a tight correlation between pulsation period and intrinsic brightness in the class of variable stars called Cepheids after their prototype, δ Cephei. The period–luminosity relation is extremely important as a standard candle that permits the determination of the distances of stars in clusters and galaxies too distant to be measured by their parallax.

One of a large number of women employed at Harvard College Observatory by director **Edward Pickering**, Leavitt was the daughter of Congregational minister Reverend George Roswell and Henrietta S. (*née* Kendrick) Leavitt, who traced their Puritan heritage to settlers at Hingham, Massachusetts in the 1640s. In 1887, Henrietta entered Oberlin College, excelling despite an inexplicable and progressive loss of hearing. She then enrolled at the Society for the Collegiate Instruction of Women, Radcliffe, where her charm and attentiveness made



her popular among her classmates, softening the often-traumatic effects of a now-profound deafness. She became immersed in astronomy while taking a course in her senior year at Radcliffe.

In 1872, **Henry Draper** had taken the first astronomical photographs that showed spectral lines in the ultraviolet as well as the visible portion of the solar spectrum. Then, during the 1880s, Pickering significantly advanced the study of the spectra of stars by employing a large prism in front of a photographic plate to capture an entire field of stars at once. As director of the Harvard College Observatory, he had ambitious plans to map the heavens using this technique. For this, he needed assistance.

Leavitt, who had begun volunteer work for Pickering upon her graduation, had to leave the observatory when a family crisis called her to Wisconsin. After 2 years, Pickering himself urged Leavitt to return at his expense. He offered to pay her 30 cents per hour (5 cents per hour more than other women working in comparable jobs at Harvard) and told her that if she had to leave the observatory again, she could take with her the materials and data she had collected. Pickering's offer of a raise in 1900 – to a woman, no less – was a rarity. Within a short time of her permanent appointment in 1902, Leavitt advanced to head the photometry department.

Almost immediately, Pickering chose Leavitt to execute his grand plan to redetermine star magnitudes using the most up-to-date photographic techniques. The accuracy of such data was crucial to astronomical investigation during this period, and Pickering's staff began with the "north polar sequence" as a standard for the entire sky. In 1904, 46 stars were selected, and 299 photographic plates taken with 13 telescopes were employed to establish this primary sequence. Leavitt and her colleagues then applied this scale to measure the magnitudes of thousands of stars in the heavens. Leavitt discovered 2,400 variable stars while making these stellar measurements, fully doubling the number of such stars known in her time.

Leavitt also observed four novae, various asteroids, and other celestial objects, and published 17 reports of her observations in the *Annals and Circulars of the Harvard College Observatory*. After Leavitt reported 843 new variables in the Small Magellanic Cloud, **Charles Young** of Princeton (in a letter to Pickering) called Leavitt a "star fiend" and professed himself both amazed and amused that he could not keep up with her.

Leavitt's groundbreaking discovery came from her examination of a very large number of images of the Large Magellanic Clouds [LMC] and Small Magellanic Clouds [SMC] (companion galaxies to our Milky Way, visible only from the Southern Hemisphere). These had been taken at the Harvard Southern Station in Arequipa, Peru, starting in 1905. Leavitt eventually found 1,777 Magellanic Cloud variables on these plates and was able to determine regular periods (ranging from less than a day to more than 100 days) for a small subset of them. In 1908, she plotted the average apparent magnitude of the LMC variables (whose light curves had a shape already known for galactic variables called Cepheids) versus the periods with which their brightness changed. Leavitt found a clear correlation, which was published under her own name in 1908.

This period–luminosity relation was detectable in the LMC because, although the galaxy's distance was not known, at least all the stars are at the *same* distance, so that apparent magnitude is a proxy for intrinsic magnitude at that distance. The absolute distances and magnitudes could be established only by measuring Cepheid distances in some other way or by understanding the underlying physics of the variability. Both have now been done, and Cepheid variables are, therefore, an enormously valuable astronomical tool for establishing the distance ladder in the cosmos (although the first calibration, by **Harlow Shapley**, was considerably in error, making the Milky Way seem larger and other galaxies less distant than they really are).

Leavitt herself was not able to follow up on her discovery until 4 years later when she confirmed the relationship with a larger number of stars in the LMC and in the SMC. Pickering believed that it was the observatory's responsibility to collect data, and it was up to others to explain them.

Leavitt's "record of progress" indicates the large number of projects she was working on simultaneously, including an investigation of Algol variables undertaken by **Henry Norris Russell**, measurements of the luminosities of stars in **Jacobus Kapteyn**'s selected areas, experiments to determine the colors of faint stars (including hypotheses on the redness of the fainter stars), methods of transforming photographic to visual magnitudes, and, with astronomers at Mount Wilson, determination of the exact photographic magnitudes of the North Polar Sequence of stars.

The information Leavitt supplied on the magnitudes of stars in the North Polar Sequence was adopted by the International Committee on Photographic Magnitudes for the Astrographic Catalogue for the *Carte du Ciel* map of the sky. By the time of her death, she had completed work on 108 areas. Astronomers interested in investigating the Milky Way referred to Leavitt's North Polar Sequence data for decades.

In 1925, the Swedish mathematician, and member of the Swedish Academy, professor Götha Mittag-Leffler sent a letter to Leavitt at the Harvard College Observatory. He wished to nominate her for the Nobel Prize in Physics for her discovery of the period–luminosity relationship that had done so much in advancing the science of astronomy. However, Mittag-Leffler was not aware that Leavitt had died of cancer. A Moon crater is named in her honor, and a memorial tablet, honoring her and the period–luminosity relation, hung for many years on the wall at Harvard College Observatory.

Harry G. Lang

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Lebedev, Petr Nikolaevich

Born **Moscow, Russia, 24 February/8 March 1866**
Died **Moscow, Russia, 1/14 March 1912**

Petr Lebedev's principal contribution to astronomy lay in demonstrating the existence of an extremely small physical pressure that light exerts on bodies. Such a pressure had been theoretically predicted by **James Maxwell**.

Lebedev was originally trained in business and engineering but then decided to study physics at the University of Strasbourg, under the guidance of August Kundt. He returned to his native land in 1891 and obtained a position at Moscow University; his first published research was on the Mossotti–Clausius theory of dielectrics. Lebedev was awarded his Ph.D. in 1900 for the above-mentioned research on light pressure. He also studied terrestrial magnetism.

Along with the solar wind, Lebedev's experimental demonstration of light pressure has helped to explain why comet tails are directed outward from the Sun. But as a politically progressive educator during a reign of reactionary conservatism, Lebedev was expelled from Moscow University and, after 1911, briefly operated his own laboratory, which was financed by private sponsors.

Lebedev was known as one of the most prominent physicists in prerevolutionary Russia. He founded the Lebedev Physical Society in Moscow. The Physical Institute of the Russian Academy of Sciences is now named after Lebedev. His name was also given to a large crater on the Moon's farside.

Alexander A. Gurshtein

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Leclerc, Georges-Louis

Born **Montbard, (Côte-d'Or), France, 7 September 1707**
Died **Paris, France, 16 April 1788**

Georges-Louis Leclerc de Buffon can be considered one of the pioneers of modern cosmogony, but is best known as a naturalist. Buffon's father, Benjamin Leclerc, was a French official; his mother was an educated woman with wealthy connections. He attended the Jesuit Collège de Godrans in Dijon and, at his father's insistence, began the study of law in 1723. By 1728, he was in Angers studying medicine, mathematics, and botany. Involved there in a duel, Buffon fled France and toured Europe in the company of the English Duke of Kingston, arriving eventually in England, where he was elected a fellow of the Royal Society.

Buffon returned to France on his mother's death to oversee the family estate at Montbard. Here he translated Stephen Hales' *Vegetable Staticks* and studied mathematics. In 1739, Buffon was appointed director of the Jardin du roi in Paris (the royal botanical garden, now the Jardin des Plantes). His work there stimulated his idea for writing a comprehensive natural history, the *Histoire* *naturelle, générale et particulière*, which appeared in 44 volumes between 1745 and 1804. (The last eight volumes were completed after his death by Count de Lacépède.) This work, the first modern systematic review of biology, anthropology, and geology, became very popular, more for its literary style and its beautiful illustrations than for its scientific accuracy. It was translated into various languages. Buffon also wrote papers about mathematics, physics, and agriculture.

The first volume of the *Histoire naturelle* contains a theory of the Earth, in which Buffon stated that the planets were made from matter ejected by the Sun through the collision of a comet. He was inspired by **Isaac Newton**'s opinion that comets were solid objects and that they could have enormous masses. (The famous comet of 1680 (C/1680 VI) was considered to have 28,000 times the Earth's mass.) The theory had to explain the initial momentum given to the planets and the fact that they all move in the same direction and nearly in the same plane. Moreover, since Newton believed that the density of the known seven planets decreased with their distance from the Sun, Buffon suggested that the less dense parts of the Sun were ejected further than the less dense. Although the idea of a comet collision is totally erroneous, it was the first scientific hypothesis about the origin of the planets based on Newton's gravitational theory. It can be considered a predecessor of the later tidal hypotheses of the origin of the Solar System by **Thomas Chamberlin** and **Forest Moulton**, and by **James Jeans**, although they were not inspired by it.

Buffon was a treasurer of the Paris Academy of Sciences, although he spent little time in Paris, undertaking most of his work on his Burgundian estate. There, he worked continuously, up to 12 hours a day, on his *Histoire naturelle*. Buffon was also a member of the Académie française, thanks to his literary talent, and various other academies. His wife died in 1769 leaving him with a 5-year-old son, later to be executed during the Revolution. Although well known during his life, Buffon was not liked by many of his fellow scientists and philosophers, particularly for his pretentious style. Ironically he is still known in France for his sentence: "Style is man himself."

Tim Trachet

Alternate name

Comte de Buffon

Selected Reference

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Ledoux, Paul

Born **Forrières, Belgium, 8 August 1914**
Died **Liège, Belgium, 6 October 1988**

Belgian theoretical astrophysicist Paul Ledoux formulated the Ledoux criterion for convective instability. In 1947 Ledoux showed that the transport of energy by convection (gas flowing up and down) inside a star is somewhat inhibited when the lower layers contain more heavy elements than the upper layers. This always happens in evolved stars that have converted their central hydrogen to helium and perhaps on to heavier elements. The star adjusts to the situation by developing a zone in which the composition varies continuously. The process is now called semi-convection and is important in determining whether later evolution will be gradual or sudden and in determining what mix of heavy elements a star will later eject in a planetary nebula or a supernova explosion.

Born on the eve of World War I, Ledoux was quickly recognise as outstanding. He studied at Liège University and graduated *summa cum laude* in physics in 1937. After his military training period, Ledoux left Belgium with his wife to work at the Institute of Theoretical Astrophysics in Oslo, Norway. There, he had numerous talks with L. Rosseland, **Vilhelm Bjerknes**, and **Carl Störmer** and, using **Arthur Eddington**'s standard model, he proved that main-sequence stars would show vibrational instability if they reached a critical mass of the order of 90 solar masses. His stay in Norway was interrupted by the German invasion of Norway and of the Low Countries. After a short stay in the Stockholm Observatory at Saltjobaden, Sweden, the Ledouxs departed *via* the Far-Eastern route to Yerkes Observatory, Wisconsin, USA where they were welcomed by director **Otto Struve**. On the advice of **Subrahmanyan Chandrasekhar**, Ledoux resumed his work on vibrational stability of stars and published two papers in the *Astrophysical Journal*. However, in September 1941 he was drafted into the Belgian Army, in Canada and Great Britain. At the end of the war, Ledoux was a member of a meteorological team in the Belgian Congo. He nevertheless tried to continue his astrophysical research and thought that the virial theorem under his differential form could be used to study the radial pulsations of stars.

After obtaining a Ph.D. degree in Belgium in 1946, Ledoux resumed his work with Chandrasekhar and succeeded in generalizing **Karl Schwarzschild**'s criterion for convection in a region of the star where the molecular weight varies. This intermediate part of the star called a semi-convective zone was later recognized as playing an important role in the evolution of massive stars. He became lecturer at Liège University in 1956 and was promoted to a full professorship in 1959, being in charge of the teaching of theoretical astrophysics, analytical mechanics, and geophysics. After a stay in Princeton University in 1951/1952, where Ledoux explained the behavior of β Cephei stars through nonradial oscillations, he was recognized as a prominent scientist in the study of stellar stability. He was chosen as the author of the important review paper on stellar structure in the *Handbuch der Physik* (Vol. 51, pp. 353–604), while he wrote the chapter on variable stars with the Leiden astronomer Thomas Walravens.

Ledoux's accomplishments were recognized with doctorates *honoris causa* of the Free Brussels University and of the Catholic University in Louvain, Belgium and visiting professorships in several renowned universities in the United States. He received the Eddington Medal of the Royal Astronomical Society before becoming an associate in 1974, and the Janssen Medal of the Institut de France, of which he became a foreign associate in 1984. Ledoux was elected in 1959 as a corresponding member of the Académie royale des sciences, Lettres et beaux-arts de Belgique, and was the director of its Class of Science in 1973. In Belgium, he was the recipient of the Prix Franqui (1964) and of the Prix Décennal des Mathématiques Appliquées. Ledoux presided over the National Committee for Astronomy and was a member of the Scientific Council of the Royal Observatory. An active member of the International Astronomical Union [IAU], he served as president of its commission on the Internal Constitution of Stars of the IAU during the 1964–1967 triennium.

A patient and even-tempered man, Ledoux's advice was welcomed in many organizations. He was a member of several committees of the European Space Agency at beginnings in the early 1960s, attracting the attention of his colleagues to the importance of exploring the infrared region of stellar spectra, a rather prophetic view as has been recently revealed by several space observatories. Ledoux played an important role in the development of the European Southern Observatory where he acted as chairman of the Observing Program Committee and later as chairman of the council. In summary, it can be said that he brought to astrophysics many new and original ideas that later have been developed by several collaborators and under the auspices of international agencies.

Léo Houziaux

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Le Doulcet, Philippe Gustave

Born **Caen, (Calvados), France, 1795**
Died **Paris, France, 1874**

Gustave Doulcet, comte de Pontécoulant, retired from the military to devote himself to mathematical astronomy. The son of a well-known politician who supported the French Revolution, he served as a captain in the army prior to 1830. Pontécoulant had been a student at the École Polytechnique.

In his *Théorie analytique du système du monde*, Pontécoulant successfully made the *Mécanique Céleste* of **Pierre de Laplace** more accessible to a popular audience in France and England and, *via* translation, in Germany. This work included Pontécoulant's calculation that the perihelion of Halley's comet (IP/Halley) would occur on 31 October 1835, within 3 days of the actual event. Pontécoulant was a member of several scientific societies; a lunar crater at latitude 58°.7 S and longitude 66°.0 E is named in his honor.

Marvin Bolt

Alternate name

Comte de Pontécoulant

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Lefrançois, Michel

Born **Courcy, (Manche), France, 21 April 1766**
Died **Paris, France, 8 April 1839**

The nephew (and adopted son) of **Joseph Lalande** narrowly missed discovering a new planet. The "star" astronomer Michel Lefrançois de Lalande observed on 8 May 1795 had moved when he reobserved it on 10 May. However, he attributed the difference in position to observational error. **Sears Walker** later showed that it was the planet Neptune.

Alternate name

Lefrançois de Lalande, Michel

Selected Reference

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Lefrançois de la Lande, Joseph-Jérôme

➔ **Lalande, Joseph-Jérôme**

Lefrançois de Lalande, Michel

➔ **Lefrançois [de Lalande], Michel**

Legendre, Adrien-Marie

Born **Paris (or possibly Toulouse), France, 18 September 1752**
Died **Paris, France, 10 January 1833**

Adrien-Marie Legendre was primarily a mathematician, publishing an important three-volume work on number theory and an equally important three-volume work on elliptic functions, and was the first to publish the method of least squares. Little is known of his early life though it is likely that he was from a well-to-do family. Legendre studied at the Collège Mazarin, graduating in 1770. He served as professor of mathematics at the École Militaire in Paris from 1775 to 1780. In 1795, Legendre was appointed a professor at the École Normale. He was married by the mid-1790s.

When **Pierre de Laplace** was promoted to an associate member of the Academy of Sciences in Paris, an *adjoint* position became opened, and Legendre was appointed to it in 1783. During the revolutionary era, Legendre was also one of the members of the Committee of Weights and Measures that established (1791) the metric system. Legendre survived the Terror, but the closure of the academy in 1793 deprived him of an income. As the Revolution had already destroyed his small fortune, Legendre was plunged into dire financial straits. Fortunately, in 1795, the academy reopened as the Institut National des Sciences et des Arts, and Legendre received one of the six positions in mathematics, which again provided him with a small income.

Legendre survived the turbulent revolutionary era only to fall from grace when he voted against a government-supported candidate for the national institute in 1824. Thereafter, the government withdrew its financial support of Legendre, and he died in poverty.

In astronomy, Legendre was first a member of the 1787 team to work with the Royal Observatory in Greenwich to measure the size of the Earth (for which Legendre became a member of the Royal Society of London in 1787). However, his main contribution came in 1805 when he published details of the method of least squares in his *Nouvelle méthode pour le détermination de l'orbite des Comètes* (New method for determining the orbit of Comets). The details appeared in an appendix, dated 6 March 1805. This caused a priority dispute with **Carl Gauss**, who claimed to have been using the method since 1795, but did not publish the details until 1809. By the strict standards of academic priority, Legendre, as the first to publish, should be considered the inventor of the method of least squares.

The problem Legendre sought to solve was the following: Any physical measurement of a quantity is subject to error. More specifically, when dealing with the planetary orbits, there are five geometrical parameters necessary to describe the elliptical orbit of an object about the Sun: the length a of the semimajor axis, the eccentricity e of the ellipse, the inclination i of the plane of the orbit to the ecliptic, the longitude Ω of the ascending node, and the argument ω of perihelion. A sixth parameter gives the actual position of the object along the elliptical orbit at a particular time. These parameters are not measured directly; instead, they emerge as the solution to a system of equations drawn from three (or more) complete observations of a celestial object. For example, if we wish to find the area of a rectangular field, we measure its dimensions and then compute its area. Thus, the determination of the orbital parameters of an object can be viewed as the solution to a system of equations in six unknowns, necessitating a minimum of three observations (with each observation supplying two of the unknowns). With more observations, the system of equations becomes overdetermined, and thus the question arises of finding the six parameters that best fit the observations.

The discrepancy between the actual position of the object (defined in relation to the six orbital elements or parameters) and the measured position of the object constitutes the error of observation. Legendre claimed (without proof) that, of all possible values for the parameters, the ones that minimized the sum of the squares of the errors were the ones most likely to be correct. Gauss gave a defective proof of the validity of this assumption, but the first rigorous justification was given by the Irish–American mathematician Robert Adrain in 1808.

Legendre also published a number of textbooks used throughout Europe and the United States. His *Éléments de géométrie* (Elements of geometry) (1794) was the principal introductory text used for nearly a century.

Jeff Suzuki

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Stigler, Stephen M. (1986). *The History of Statistics*. Cambridge, Massachusetts: Harvard University Press.

Leibniz, Gottfried Wilhelm

Born **Leipzig, (Germany), 1 July 1646**
Died **Hanover, (Germany), 14 November 1716**

Gottfried Leibniz was one of the most universal scholars Europe has produced: a mathematician, a philosopher, and a logician of the first order, as well as a considerable physicist, historian, jurist, and diplomat. His father, Friedrich Leibniz, was a professor of moral philosophy at the University of Leipzig. His mother Catherina, Friedrich's third wife, was the daughter of a prominent jurist and a very pious woman who took care of Gottfried and his two half siblings once her husband died in 1652. Leibniz was a very precocious child who spent many an hour in his father's library and taught himself Latin by reading Livy. His formal education took place at the University of Leipzig where he earned a degree in law in 1665. In 1672, Leibniz went to Paris, where he stayed until 1676. The Parisian period was crucial to his intellectual development, for there he was exposed to Cartesianism, and became acquainted with the leading thinkers of his time, including **Nicolas Malebranche** and **Christiaan Huygens**. By the end of his stay in Paris, Leibniz had invented the calculus, although he postponed its publication until 1684. This invention later became the source of a very acrimonious dispute with **Isaac Newton**, who, although he had invented his own version in the mid-1660s, did not publish it until 1693. Though the evidence suggests that Leibniz and Newton invented the calculus independently, it was Leibniz who produced the principal notation that is still in use and who had the greatest impact on the discipline through the work of his immediate followers, such as Guillaume de l'Hospital.

At the end of 1676, Leibniz became librarian to the Duke of Brunswick at Hanover, a post he held for the rest of his life. He traveled for some time in Italy to collect material for his history of the house of Brunswick, which, however, never saw the light of day. Perhaps because of this failure, and perhaps in part because of personal dislike, when Georg Ludwig, the Duke of Brunswick, became king of England as George I in 1714, he did not take Leibniz along to London as a court historian, in spite of Leibniz's pleas. Leibniz was compelled to remain in Hanover, where he died almost in disgrace.

Leibniz's astronomical contributions are to be found in his efforts at explaining planetary motions. Like Huygens, he never accepted Newtonian gravitation because of its apparent mechanical inexplicability. Quite reasonably, Leibniz became convinced that according to the Newtonians gravity is a primitive property of matter, that is, a property not further explainable in material terms. Although Newton, at least publicly, professed agnosticism on whether gravity is primitive to matter or not, some of his followers, such as **Roger Cotes**, seem to have been ready to think of universal gravitation as primitive in the sense of being essential to matter, and others, such as Samuel Clarke, publicly held that gravitation is a primitive feature of matter ultimately caused by continuous divine intervention. Leibniz took these views to be poor science and worse theology. As a result, although he clearly understood Newton's revolutionary achievement in connecting mechanics and astronomy in the *Principia*, he tended to play down its physical significance. Even if Newton had shown the exact mathematical relation between centripetal forces and **Johannes Kepler**'s area law, he had not given any explanation of them. In this respect, Newton had provided a clever mathematical model but not a physical explanation of the motions of the planets. **René Descartes**'s vortices, by contrast, provided a physical explanation of the motion of the planets, but a mathematically incorrect one, since, for example, Kepler's area law cannot be derived from it. Leibniz saw himself as providing a vortical theory that also is mathematically correct.

Leibniz's attempt is the *Tentamen De Motuum Coelestium Causis*, published in 1689 and, contrary to his claims, composed after he had seen Newton's *Principia*. In it, he argued that since all bodies tend to move uniformly and to recede along the tangent when moving in a curve, planets must be constrained and moved by an ethereal matter because their motion is not uniform – they move faster when closer to the Sun – and curved. Leibniz then supposed that this subtle matter moves around the Sun with harmonic motion, with a speed that is inversely proportional to the distances, or radii, from the Sun. Each planet floats in this fluid and is endowed with two motions: a transradial one in which it is carried by and moves exactly like the fluid (harmonically), and a radial motion, which Leibniz called "paracentric," in which it moves along the radius from layer to layer of the fluid. The paracentric motion itself is the result of two radial impulses, a gravitational one, the mechanism of which Leibniz did not explain, and a centrifugal one arising from the planet's transradial motion and measured by the square of the transradial velocity divided by the distance from the center. The transradial harmonic motion provides Kepler's area law, while the positing of a Keplerian elliptical orbit traversed with such a harmonic motion produces the inverse-square law of gravitation.

Although, at the end of the *Tentamen* Leibniz had to admit that in spite of the fact that his mechanical model of planetary motion involved a centripetal impulse toward the Sun, he had not provided an explanation of gravity. In letters, notes, and personal reworkings of the *Tentamen* he considered various mechanical models, apparently favoring two. One involved a fluid propagating from the center in accordance with the inverse-square law, in analogy with light. The fluid penetrated bodies through their pores, and since there was less receding fluid in them than elsewhere, they were pushed back toward the center in proportion to the number of their pores. The other was a modification of Huygens's model for terrestrial gravity based on fluid matter moving in all directions on spherical surfaces around the Earth. Leibniz assumed the equality of *vis viva* in each circle of fluid, suggesting that it could explain the stability of the fluid system, and managed to infer Kepler's third law and the inverse-square law.

The *Tentamen* was vehemently criticized by Newton and his followers, who argued that it bristled with errors. **John Keill**, giving public voice to Newton's views, called it "the most absurd piece of philosophy ever written." However, some of Newton's mathematical criticisms were ill taken, and some of the physical ones did not fare much better. For example, the claim that a vortical theory of attraction entails that bodies are pushed to the axis of the vortex and not to the center was based on Leibniz's mostly rhetorical praise of the alleged vortex theory of gravitation by Descartes, and not on Leibniz's actual unpublished models which, like Huygens's, overcome the problem. Similarly, E. J. Aiton has argued that Newton's critique of Leibniz's notion of centrifugal force as not being equal and opposed to gravitational force missed the point that Leibniz was working within a framework that owed more to Huygens than to him.

Still, Leibniz's theory did have very serious problems, some of which were pointed out early on. In spite of Leibniz's attempts, Huygens, whose rejection of nonmechanical gravitation was as firm as his, could not see the need for the harmonic vortex. He asked Leibniz why the harmonic vortex is necessary given Newton's system, in which "the movement of the planets is explained by the heaviness towards the Sun and the *vis centrifuga* which are in a balance." *Vis centrifuga* aside, Huygens's question was about the apparent redundancy of Leibniz's theory: Why did Leibniz want the harmonic vortex in addition to that which produces gravity? Leibniz replied that one reason was that the harmonic vortex explains why all the planets move roughly in the same plane and in the same direction, while a theory like Newton's cannot.

Huygens and **James Gregory** also noted that Leibniz's system fails to produce a satisfactory account of the motion of comets because they would be impeded by the Leibnizian vortices. Leibniz answered that the vortex does not significantly impede the motion of comets passing through it, although it does conserve the motion of planets in it. But even if one were to accept Leibniz's answer, his theory suffers from other problems. For one thing, how the fluid in harmonic motion can offer no resistance to radial motion while pushing the planet transradially is unclear. Nor is it clear how the harmonic vortex and the gravitational vortex postulated in an attempt to explain gravitational impulses can avoid interacting. More seriously, the harmonic vortex transports the planet, which therefore moves according to Kepler's law of the areas, but it is the gravitational vortex that rotates in accordance with Kepler's third law; in the end, Leibniz could not account for Kepler's three laws together.

Ezio Vailati

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Lemaître, Georges Henri-Joseph-Edouard

Born **Charleroi, Belgium, 17 July 1894**
Died **Charleroi, Belgium, 20 June 1966**

Belgian mathematician and theoretical cosmologist Georges Lemaître was the first to recognize that a number of things that are now taken to be important and obvious must be true about a general-relativistic universe (including the fact that it must expand). He was the son of Joeseph Lemaître and Maguerite Lannoy and received his basic education at a Jesuit school in Louvain, Belgium. He enrolled in 1911 as an engineering student at the city's Catholic University, but with the outbreak of World War I was called to service as an artillery officer, for which he was decorated. Returning to Louvain, Lemaître received a first degree in mathematics and physics in 1920, then enrolled in the Malines seminary. He was ordained as a priest in 1923 and was thereafter often referred to as Abbé Lemaître. Following his 1936 election to the Pontifical Academy of Sciences he was addressed as Monseigneur.

Lemaître spent the year 1923/1924 at Cambridge, England, studying solar physics and other topics with **Arthur Eddington**, and the years 1924–1926 in the United States, traveling widely, but primarily at Harvard University and the Massachusetts Institute of Technology [MIT]. His Ph.D. dissertation, awarded for the degree at Louvain in 1927, was partially prepared at MIT. It included early forms of a number of the ideas in relativity and cosmology that he published over the next decade. Lemaître was appointed to a professorship at Louvain and remained there the rest of his career, keeping some work in physics and astronomy alive during the very difficult years of World War II, when the staff was sometimes reduced to starvation wages. From the mid-1930s onward, he remained an authority on cosmology, but focused increasingly on topics like celestial mechanics and the motion of charged particles in the magnetic fields of the Earth and galaxy. These problems could be solved only by numerical methods, and Lemaître and his students did pioneering work in the exploitation of electronic computers and in setting up a computer laboratory in Louvain.

Lemaître scored a large number of "firsts" in relativity and cosmology between 1927 and 1934.

(1) He recognized that what is now called the Schwarzschild radius or horizon (for **Karl Schwarzschild**) at $R = 2GM/c^2$ is not a real singularity, so that physical objects can exist inside and outside of it. His thesis included a version of what is now called the Tolman–Oppenheimer–Volkoff equation of state, which permits calculating the structure of such objects.
(2) He demonstrated that the static universe of **Albert Einstein** is unstable and will eventually begin a runaway expansion or contraction. At various times, he supposed that the initial state of the Universe was close to this static model; at other times he contemplated many billions of years of alternating expansion and contraction, with us living in an expansion epoch extending for the past nine billion years or so.
(3) He wrote down the equations describing expanding space-time, in somewhat the same form as **Alexander Friedmann**, but also

recognized that these equations could pertain to the real, physical Universe.

(4) He incorporated the redshifts measured by **Vesto Slipher** into these equations and so found a value of 600 km/s/Mpc in 1927 for what is now called the Hubble constant. **Edwin Hubble**'s own, first, 1929 value for this was about 500 km/s/Mpc, and modern ones are in the range 55–70 km/s/Mpc.

(5) He pioneered the idea that physical conditions in the early Universe must have been very different, suggesting a cosmic egg or primordial atom, with a mass equal to the total mass of the Universe as then understood (enough to make a few billion galaxies of a few billion stars each) and density equal to that of an atomic nucleus, hence a "primordial atom." It would have had a radius only about 30 times that of the Sun.

(6) He was the first to show that Einstein's cosmological constant had a physical interpretation as a vacuum energy density that would exert negative pressure, and he held onto the idea that this was likely to be important in the real universe when Einstein and nearly everybody else abandoned the idea of a cosmological constant after 1929. It is part of modern cosmology, including Lemaître's negative-pressure interpretation.

Lemaître, in collaboration with Mexican physicist Manuel Vallarta, had suggested that cosmic rays (very high energy particles that pervade the galaxy) might be remnants of the primordial atom. It is now thought that they are largely accelerated by supernovae and their remnants. But Lemaître lived to hear from his successor at Louvain about the discovery of the 2.7 K cosmic microwave background radiation, which really is such a relic.

Lemaître received the prestigious Belgian Prix Franqui and was the first Eddington Medalist of the Royal Astronomical Society (London) in 1951. He served as president of the Pontifical Academy of Sciences from 1960 to 1966.

As a priest and cosmologist, Lemaître was very much aware of the problematic relationship between the Christian dogma of a world created by God and the scientific theory of a universe starting in a Big Bang. However, contrary to some other cosmologists (as well as theologians), he was careful not to confuse science and theology and not to use one of the fields as legitimization for the other. Lemaître believed that science and theology were separate fields and that cosmology neither confirmed nor refuted the Christian notion of a world created by God. This he made clear in his address to the 1958 Solvay meeting, where he pointed out that theoretical cosmology "remains entirely outside any metaphysical or religious question."

Helge Kragh

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Lemonnier, Pierre-Charles

Monnier, Pierre-Charles le

Leovitius, Cyprianus

Born **Hradisch, (Czech Republic), 1524**
Died **Lauingen, (Bavaria, Germany), 1574**

Cyprianus Leovitius: **Tycho Brahe** used the ephemeris prepared by this Czech astrologer.

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Lepaute, Nicole-Reine

Born **Paris, France, 5 January 1723**
Died **Saint-Cloud near Paris, France, 6 December 1788**

Nicole Lepaute participated with **Joseph–Jérôme Lalande** and **Alexis–claude Clairaut** in their calculations relating to comet P1/Halley. She also calculated solar eclipses and astronomical ephemerides. She is among the few women whose active participation in 18th-century science has been recognized. Lalande, in his *History of Astronomy*, paid tribute to her.

Nicole Reine Étable de la Brière was born in the Palais de Luxembourg, where her father was in service to the Queen of Spain, Elisabeth d'Orléans. In her childhood, she was recognized for her intelligence, love for and interest in books, and for her social gifts. Lepaute was fond of mathematics. On 27 August 1748, she married Jean André Lepaute, who later became the royal clockmaker.

From 1753, Jérôme Lalande had his observatory located at the main entrance to the Palais de Luxembourg; he had taken it over from **Joseph Delisle** when the latter moved to Saint Petersburg. Given the proximity of the observatory to Lepaute's residence, she and Lalande soon became acquainted. He reports that she observed and contributed to discussions and calculations. She also assisted her husband, producing tables of the number of oscillations per unit time for pendulums with different lengths. These results were inserted in the supplement to the *Traité d'horlogerie* published under her husband's name in 1760.

In the 1750s, the astronomical community was much interested in the return of the comet that **Edmund Halley** had predicted would return in 1758. In 1757, Lalande invited **Alexis–Claude Clairaut** to estimate the gravitational effects due to Jupiter and Saturn on the comet's orbit and to make a precise prediction for the date of its return. He also suggested that Lepaute might participate in the calculations. They calculated both the distance and the force due to each of the two perturbing planets for every degree along the comet's orbit for a 150-year period. In November 1758, some short delay in the comet's return could be announced to the academy.

In 1762, Lepaute was also involved in the calculations of the path and circumstances of an annular eclipse that was to occur on 1 April 1764. Many visibility shadow tracks for Europe and for Paris, with the time and percentage of the eclipse, were published and distributed to the public. Lepaute contributed to the annual *Connaissance des temps* of which Lalande was in charge; also for Lalande, she took an active part in computing ephemerides for Volume 8 (1784–1792) and, on her own, undertook the calculations for the first 2 years of Volume 9 (for 1793–1800) of the decennial publication *Ephémerides des mouvements célestes*, which Lalande edited from 1775.

Lepaute was a member of the Académie royale des sciences de Béziers, to which she presented some calculations relating to observations made during the 1761 Venus transit. Lalande reported that Lepaute's ceaseless calculations affected her eyesight, forcing her to abandon her scientific activities prematurely. Lepaute and her ailing husband moved to Saint-Cloud, where she died just 4 months before him. They had no children, but she cared for children from his family, introducing her nephew Joseph Lepaute Dagelet to astronomy. He became a member of the Royal Academy of Sciences in 1785 but died in the wreck of the ship *La Pérouse*.

Lalande paid tribute to Lepaute's talent and courage as she undertook the main part in the very laborious cometary computations. According to Lalande, Clairaut did the same but, for personal reasons, removed the words of acknowledgment from his work. According to Clairaut, Lepaute was *la savante calculatrice*.

Monique Gros

Alternate name

Étable de la Brière, Nicole-Reine

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Lescarbault, Edmond Modeste

Born **Châteaudun, Eure-et-Loir, France, 11 August 1814**
Died **Orgères, Orne, France, 1894**

A single observation by Edmond Lescarbault set off a decade-long but futile search for Vulcan, supposedly orbiting the Sun closer than Mercury. As a student, Lescarbault studied medicine and produced a thesis on typhoid fever, enabling him to serve as a country physician in Orgères, 75 miles southwest of Paris, from 1848 until 1872. But his passion was astronomy, and for it he constructed an observatory equipped with a refractor, a pocket watch, and a seconds pendulum, as well as a wooden board on which he did his computations.

The discovery of Neptune had been prompted by calculations carried out by **Urbain Le Verrier** concerning the irregularities of Uranus's orbit; Le Verrier also suggested that a similarly unknown planet could explain observed discrepancies in Mercury's orbit. Lescarbault read of Le Verrier's work, and informed him that on 26 March 1859, Lescarbault had observed an unusual black dot moving across the face of the Sun. He noted that it had transited the Sun in about 4.5 hours, and measured the inclination of its orbit as approximately 6°. His experience suggested that it was not an ordinary sunspot at all, but he delayed until December to inform Le Verrier, who immediately hurried to visit the doctor to substantiate the report. After interrogating the physician, and inspecting his observatory, Le Verrier became convinced of Lescarbault's credibility. Le Verrier named the putative planet "Vulcan," and had Lescarbault honored as a *Chevalier* (knight) of the French Legion of Honor, a title that was later taken away. A street in Orgères, however, still bears the name of Lescarbault.

In 1877, Le Verrier's list of half a dozen observations of Vulcan from 1802 to 1862 appeared in the Royal Astronomical Society's *Monthly Notices* along with a plea for astronomers to look for Vulcan. From his collected observations, Le Verrier had determined Vulcan's mass and orbital parameters, and even the date of a future transit: 22 March 1877. No one saw it then, or during the solar eclipses in 1860 or 1878, but several observations of something that might be Vulcan continued to be reported in various journals. **Johann Wolf**, as well as other astronomers, noted several "spots" that seemed to agree with a planet traveling in a sub-Mercury orbit.

Even so, the lack of consistent confirming observations made it clear that Vulcan did not exist, and that Lescarbault was not another **William Herschel**. The advancement of Mercury's perihelion would soon be explained instead by **Albert Einstein**, whose theory of general relativity removed Vulcan from the inventory of the Solar System and Lescarbault from the list of astronomical discoverers.

Archival papers of Lescarbault, and manuscripts with his annotations, are in the Municipal Library of Châteaudun.

Marvin Bolt

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Leucippus of Miletus

Born **Miletus (near Söke, Turkey), *circa* 480 BCE**
Died ***circa* 420 BCE**

Leucippus was said by **Aristotle** and others to be the originator of the idea of atoms.

Little is known about the life of Leucippus; it is thought that he founded the school at Abdera on the coast of Thrace near the mouth of the Nestos River. His most famous student was **Democritus**.

Aristotle, **Theophrastus**, and Diogenes Laertius refer to Leucippus as the first person to develop the basic ideas of atomism. It is difficult for modern scholars to separate his specific contributions to the theory from those of Democritus. However, Theophrastus, who studied under Aristotle in Athens and became the head of the Lyceum there after Aristotle (*circa* 323 BCE) seems to have been able to identify the major tenets of Leucippus's thinking, which can be summarized as follows: (1) both matter and void exist; (2) matter is composed of an infinite number of elements (*i. e*., atoms), which have an infinite variety of shapes and are always in motion; and (3) innumerable worlds of differing sizes are constantly being formed and destroyed by the interactions of various conglomerations of the elements.

Two written works are attributed to Leucippus: *Megas diakosmos* Great World System, *circa* 440–430 BCE) and *On Mind*. Diogenes Laertius briefly describes the cosmology found in the first work, which resembles earlier Ionian cosmologies (IX, 31; cited in Kirk *et al*., pp 416–418):

> The worlds come into being as follows: many bodies of all sorts of shapes move "by abscission from the infinite" into a great void; they come together there, and produce a single whirl, in which, colliding with one another and revolving in all manner of ways, they begin to separate, like to like. But when their multitude prevents them from rotating any longer in equilibrium, those that are fine go out towards the surrounding void as if sifted, while the rest "abide together" and, becoming entangled, unite their motions and make a first spherical structure. This structure stands apart like a "membrane" which contains in itself all kinds of bodies; and as they whirl around owing to the resistance of the middle, the surrounding membrane becomes thin, while contiguous atoms keep flowing together owing to contact with the whirl. So the earth came into being, the atoms that had been borne to the middle abiding together there. […] Some of these bodies that get entangled form a structure that is at first moist and muddy, but as they revolve with the whirl of the whole they dry out and then ignite to form the substance of the heavenly bodies.

Diogenes attributes some other intriguing ideas to Leucippus (the Earth is "drum-shaped," solar and lunar eclipses are explained by the tilting of the Earth). These particular accounts are somewhat incomprehensible, leading most scholars to speculate that this part of the text is inaccurate, and that there may be *lacunae*.

Overall, the significance of the early atomists can be overstated; nevertheless, it seems clear that this incipient form of a materialist paradigm contributed to the development of a more scientific astronomy. "The connexions between Democritus and Newton are evident; and it would be absurd to deny the link between ancient and modern atomism …" (Barnes, p. 343). However, this was scientific speculation in, as J. Barnes puts it, "the old Ionian fashion" – neither myth, nor abstract philosophy – but not strictly based on observation and experimentation in the modern sense.

Kenneth Mayers

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Leuschner, Armin Otto

Born **Detroit, Michigan, USA, 16 January 1868**
Died **Berkeley, California, USA, 22 April 1953**

Armin Leuschner headed the astronomy department of the University of California at Berkeley for four decades, building what was widely accepted as the top graduate program in the United States and educating a number of the leading astronomers of the 20th century.

Leuschner's widowed mother took him to Germany in his infancy. Thus, although born in Detroit, he spoke English with a strong German accent. At 18, Leuschner finished the Gymnasium in Kassel and returned to the United States. Two years later, in 1888, he received his A.B. degree from the University of Michigan.

Leuschner then became the first graduate student at the new Lick Observatory, where director **Edward Holden** assigned him a photometry project. After a year, it was decided that he would alternate courses in mathematics and physics on the Berkeley campus of the University of California with research on Mount Hamilton.

Leuschner soon found that he liked the university and mathematics, and he did not like working under Holden, who was steadily arousing the enmity of the staff he had selected for the first mountaintop observatory. In 1890, Leuschner was appointed an instructor in mathematics at Berkeley, and a couple of years later an assistant professor. While still in the mathematics department, he took over the course in practical astronomy taught to civil engineers, and his title was changed to assistant professor of astronomy and geodesy.

Leuschner married Ida Louise Denicke, the daughter of influential University of California regent and wealthy San Francisco businessman Ernst A. Denicke, in 1896. They had three children. Leuschner spent the year 1896/1897 in Berlin, earning his Ph.D.

with high honors for a thesis on determining the orbits of comets. He had found his field, and it did not require living on a mountaintop or working under the by-now-hated Holden. On his return to Berkeley, Leuschner was promoted to associate professor of astronomy and geodesy and director of the Students' Observatory.

After Holden was forced to resign his position in 1897, relations between the Berkeley and Lick astronomical departments of the University of California, as they were soon titled, improved greatly. Leuschner worked well with Lick directors **James Keeler** (who died after 2 years in office) and **William Campbell** (who held the title for 30 years, the last 7 while also president of the University of California).

Keeler established the Lick fellowships to support graduate students who divided their time between studying mathematics, physics, and theoretical astronomy at Berkeley and doing research on Mount Hamilton under the Lick staff. While most of them did theses in astrophysics, they all learned a considerable amount of mathematics and theoretical astronomy at Berkeley. It is said that only one graduate student managed to obtain his Ph.D. without calculating an orbit for a comet or asteroid.

From 1907, until his retirement in 1938, Leuschner was professor of astronomy and director of the Students' Observatory. It was renamed the Leuschner Observatory in 1951 and moved off-campus in the 1960s.

Although he published a few early papers involving observations, Leuschner was very much a theoretical astronomer. His specialty was celestial mechanics, and his main contribution to research was the Leuschner method of calculating the orbits of asteroids or comets as soon as three observations were available. It was the custom at Berkeley for students to race to compute the first orbits of newly discovered objects. Such computations might take days with pencils and six-digit tables of logarithms, for which Leuschner's method was optimized. Other methods became more advantageous once desk calculators became available, but Leuschner and his staff insisted on the use of his method even in cases where the older, Gaussian method was superior. One of the objects whose orbit was first computed at Berkeley was the newly discovered planet Pluto.

When **James Watson**, who had directed the observatories of the Universities of Michigan and Wisconsin, died in 1880, he left a substantial bequest to the National Academy of Sciences, most of it to support determination of the orbits of the 22 asteroids he had discovered. Leuschner served for many years as chairman of the board of trustees of the Watson Fund of the academy, and used some of its income to support his Berkeley students. Much of his research effort was devoted to computing the orbits of Watson's minor planets, working with his former graduate students, Anna Estelle Glancy and Sophia Levy.

Two years before his retirement, in 1936, Leuschner presented to Berkeley provost Monroe Emanuel Deutsch a "summary of the present activities and standing of the men and women trained by the university for the profession of astronomy." He discussed 51 men and 12 women who had done graduate work in his department. The first two, **William Wright** and **Frederick Seares**, both Berkeley graduates, left in the 1890s without completing their Ph.D.s, but by 1936 Wright was the director of the Lick Observatory and Seares the assistant director of the Mount Wilson Observatory.

The remaining 61 completed their Ph.D.s at Berkeley (two of them in mathematics), and they included many more prominent astronomers, such as Dinsmore Alter, Priscilla Fairfield Bok, **Ralph Curtiss**, **Edward Fath**, Samuel Herrick, Jr., Hamilton Moore Jeffers, **Nicholas Mayall**, **Paul Merrill**, **Charlotte Moore** (later **Sitterly**), **Seth Nicholson**, **Frank Ross**, **Roscoe Sanford**, **Joel Stebbins**, **Peter van de Kamp**, and **Fred Whipple**. Leuschner proudly pointed out that nearly all were primarily engaged in research, many at the most prestigious observatories, and that 14 were or had been observatory directors.

Four more – Russell Tracy Crawford, Sturla Einarsson, William Ferdinand Meyer, and **Charles Shane**—had been hired by Leuschner as professors of astronomy at Berkeley. The only non-Berkeley Ph.D. who joined the department during Leuschner's time was **Robert Trumpler**, who transferred from the Lick Observatory. In addition, two of Leuschner's doctoral students, Sophia Hazel Levy (later McDonald) and Raymond Henri Sciobereti, were on the mathematics faculty at Berkeley and were continuing astronomical research. Leuschner noted that his department was ranked the best in the country in more than one survey at that time.

Leuschner held many leadership posts in the University of California, including dean of the graduate school and chairman of the board of research. One of the founders of the American Association of University Professors, he served as its president from 1923 to 1925.

Leuschner's honors included the James Craig Watson Gold Medal of the National Academy of Sciences in 1916, the Catherine Wolfe Bruce Gold Medal of the Astronomical Society of the Pacific [ASP] in 1936, and the David Rittenhouse Medal of the Franklin Institute in 1937. He served as president of the ASP three times and at the time of his death was its last charter member.

Leuschner's papers are in the Bancroft Library, University of California, Berkeley. Much of his correspondence can be found in the Mary Lea Shane Archives of the Lick Observatory, University of California, Santa Cruz.

Joseph S. Tenn

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Le Verrier, Urbain-Jean-Joseph

Born **Saint-Lô, Manche, France, 11 March 1811**
Died **Paris, France, 23 September 1877**

Urbain-Jean-Joseph Le Verrier explained the unruly behavior of Uranus by positing the existence of an unknown planet, which was subsequently discovered and named Neptune. His father, Louis-Baptiste Le Verrier, a civil servant, and mother, Pauline de Baudre, came from the lower Norman aristocracy. Their only son received his lycée education in Cherbourg, and failed the entrance examination to the École Polytechnique on his first try but was admitted in 1831. In 1837, he married Lucille Marie Clothilde Choquet, the daughter of his former teacher. They had three children: Léon, Lucille, and Urbain.

In 1837, Le Verrier was offered a position in geodesy and machines as an assistant to **Félix Savary** at the École Polytechnique. After Savary's death a few years later, Le Verrier succeeded him in the chair of astronomy. He devoted his attention to celestial mechanics to reclaim the heritage of **Pierre-Simon de Laplace**. His first memoir presented to the Paris Academy of Sciences addressed Laplace's solution to the stability of the Solar System. Later, Le Verrier laid the groundwork for a new theory of Mercury's orbit and successfully tackled the theory of several recently discovered periodic comets, on the basis of which he was successful in his bid for memberships in the academy on 19 January 1846.

Two months earlier, Le Verrier had published his first memoir on Uranus's orbital irregularities, a work he had undertaken with encouragement by **François Arago**. By revising calculations by **Alexis Bouvard** concerning the perturbations on Uranus's orbit by Jupiter and Saturn, Le Verrier lowered the value of the observed anomaly. In his second memoir, read on 1 June 1846, he boldly asserted the impossibility of explaining the remaining anomaly in terms of gravitation forces exerted by the Sun and the known planets. Without questioning **Isaac Newton**'s universal law of gravitation, Le Verrier concluded that a hypothetical planet could account for observed irregularities and determined a position based on an orbit in the ecliptic plane and Bode's law that suggested a radius twice that of Uranus.

In his third memoir, read on 31 August 1846, Le Verrier gave more precise limits within which one should look for the new planet and even predicted its apparent size. His letter to Berlin astronomer **Johann Galle** directly led to Galle's discovery of Neptune on 23 September 1846. Even in the controversy surrounding a similar prediction by **John Adams**, Le Verrier's sudden fame was not lessened by priority claims about this striking triumph of mathematical physics.

As early as 1847, Le Verrier drafted a plan for the future of astronomy that would keep him busy for the rest of his life. Aside from a minor project to reduce the positions of many fundamental stars and correct values given by **Friedrich Bessel**, he planned to track down every discrepancy between theoretical tables and actual observations of the planets. To determine the motion of planets, he would compute the 469 terms of the perturbation function. For each discrepancy with observation, Le Verrier would try to modify the mass of the perturbing planets, or else look for other causes of perturbation. His study of the motions of the Sun and the inner planets led to him to conclude that the secular motion of Mercury's perihelion was larger than expected by 38 arcsec per century. He also improved the measured values of the solar parallax (a 3% increase), the mass of Mars (a 10% decrease), and the mass of the Earth (a small increase).

Mercury's secular anomaly remained as the only significant unexplained discrepancy. In 1859, Le Verrier doubted that a planet orbiting closer to the Sun would account for the anomaly, arguing that that it would already have been observed. Considerable excitement was aroused by **Edmond Lescarbault**'s alleged observation of a planet transit over the surface of the Sun at the end of 1859. Le Verrier endorsed his observations and led a French party to Spain to observe the total solar eclipse on 18 July 1860 in the vain hope of seeing Lescarbault's planet. Le Verrier had nonetheless firmly established the existence of Mercury's secular anomaly, which would be explained by **Albert Einstein**'s theory of general relativity. For this work, he was awarded the Gold Medal of the Royal Astronomical Society in 1868. In 1876, he received it again after having formulated theories of the motion of Jupiter, Saturn, Uranus, and Neptune.

In 1854, Le Verrier was placed in charge of the Paris Observatory, replacing Arago. At the same time, the imperial regime restructured French astronomical institutions, making the observatory independent of the Bureau des longitudes and granting its director greater authority. Le Verrier pursued Arago's effort to equip the observatory with the latest precision technology, reorganized work, and established stricter observation routines, emphasizing the reduction and regular publication of observations and encouraging the discovery of new asteroids. Feeling that the Paris environment was a hindrance to some delicate instruments, such as **Jean Foucault**'s great telescope, he reorganized the Marseilles Observatory in 1862 as a branch of the Paris Observatory. Le Verrier trained a younger generation of astronomers and meteorologists such as **Jean Chacornac**, **Camille Flammarion**, **Emmanuel Liais**, Edme Hippolyte Marié-Davy, **Georges Rayet**, **Édouard Stéphan**, and **Charles Wolf**. He endeavored to make the observatory a useful auxiliary to the modern industrial state. Le Verrier organized a meteorological service using telegraphy to gather observations from the whole country and foreign observatories and to dispatch daily forecasts. Through the telegraph, he synchronized public clocks in Paris in the 1870s. In 1864, Le Verrier founded the Association française to sponsor scientific research and diffuse its discoveries into civil society.

Le Verrier's heavy-handed control over astronomy in France was strongly resisted. In 1854, Arago's former assistants were pushed out, and the Academy of Science and the Bureau des longitudes were used as strongholds for independent astronomical research. Throughout the 1860s, Le Verrier engaged in epic fights at the academy, in particular with **Charles Delaunay**, whose lunar theory he vigorously attacked. Le Verrier's personnel also resented his autocratic leaning. After Liais and Flammarion were forced out, they fought a public vendetta against Le Verrier. By the beginning of 1870, the atmosphere inside the observatory had soured to such a degree that all 14 astronomers working there resigned *en bloc*, and brought on Le Verrier's dismissal. After his successor Delaunay's untimely death in 1872, he was called again to the observatory directorship, where his somewhat smoother second term ended with long illness and death on the 41st anniversary of Neptune's discovery.

Le Verrier was made a member of the Bureau des longitudes, while a chair in celestial mechanics was created for him at the Sorbonne (the University of Paris). After the reestablishment of the Republic in 1848, Le Verrier was elected to Parliament, to take care of educational reforms and questions related to telegraphy and railways. In 1852, Emperor Napoléon III called him to the Senate.

David Aubin

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Lexell, Anders Johan

Born **Turku, (Finland), 24 December 1740**
Died **Saint Petersburg, Russia, 11 December 1784**

Anders Lexell was the first Finnish astronomer and mathematician of international fame. He was the first to suggest the modern view of short-term comets. His parents were Jonas Lexell, a goldsmith and politician, and Magdalena Catharina Björkegren. Lexell never married.

Lexell studied in Turku, obtaining a master's degree in 1760, and then moved to Uppsala. In 1763 he became a docent of mathematics in the Academy of Turku. However, he found the international connections too limited. In 1768 Lexell sent a paper on integral calculus to **Leonhard Euler**, who was then with the Saint Petersburg Academy of Sciences, and applied for a job. He was nominated an adjunct, and moved to Saint Petersburg. In 1771 Lexell became professor of astronomy. He enjoyed the work in the academy with Euler, and although he was invited as a professor to the Academy of Turku in 1775, he never went there, and finally resigned his Turku post. After Euler's death in 1783, Lexell was elected his successor as the professor of mathematics in the academy. He held the chair only for a short time; he died after suffering from a tumor.

The orbit of the comet found by **Charles Messier** in 1770 had turned out to be problematic; a parabolic orbit typical for comets did not fit the observations. Lexell found that the orbit was an ellipse with an orbital period of only 5.6 years. However, the comet was never seen again. Lexell realized that the comet had passed close to Jupiter in 1767; the encounter had made the orbit elliptical, and another encounter had ejected it from the Solar System. Thus he was the first to suggest the currently accepted model of short-period cometary orbits. Since the motions of the satellites of Jupiter were not affected, Lexell also concluded that the mass of the comet must be very small.

In 1780/1781 Lexell made a trip to Germany, France, England, the Netherlands, and Denmark. In March 1781 **William Herschel** detected a new object, which was first considered a comet. Lexell, who was then in London, found that the observations could be explained if the object moved on a circular orbit. Therefore, it was not a comet but a new planet, originally called Georgium Sidus in honor of King George III, but later renamed Uranus.

In addition to these contributions Lexell wrote about 60 papers on mathematics and astronomy, the topics of which included the solar parallax, lunar and cometary theory, differential equations, elliptic integrals, and geometry. He published most of his works in the volumes of the Saint Petersburg Academy of Sciences. In 1935 Lexell was honored by having a lunar crater (35°8 S, 4°.2 W) named for him.

Hannu Karttunen

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Li Chunfeng

Born **Yong County, Qizhou, (Shaanxi), China, 602**
Died **China, 670**

Li Chunfeng contributed to the study of armillary spheres and to the improvement of the calendar. His father, Li Bo (Huangguanzi), his son Li Yan, and his grandson Li Xianzong all served as *Taishiling* (director of the Imperial Bureau of Astronomy and Calendrics). Li Chunfeng fully understood astronomy, mathematics, and divination. He was appointed *Jiangshilang* (a low-level official post) in the *Taishiju* (Bureau of Astrology and Historiography) in the early Zhenguan

(627–648) period because of his objection to the Wuying calendar of Fu Renjun. In the 7th year of the Zhenguan period (633), Li Chungfeng made an armillary sphere, which was the first design using the three-layer armillary. At the same time, Li Chungfeng wrote *Faxiang zhi* (A history of instruments and their uses) in seven volumes for the emperor. It summarized and analyzed ancient armillary spheres.

Li Chunfeng was promoted several times to official posts: *Chengwulang*, *Taichang*, and *Taishicheng*. He edited the *Tianwen zhi* (Monograph on astronomy and astrology), *Lüli zhi* (Monograph on harmonics and the calendar), and *Wuxing zhi* (Monograph on the five phases) in both the *Jin shu* (History of the Jin dynasty) and *Sui shu* (History of the Sui dynasty). The *Tianwen zhi* of the *Jin shu* summarized the history of astronomy in ancient China in greater detail than ever before. In about 648, Li Chunfeng was promoted to *Taishiling*.

In 664, Li Chunfeng worked out the Linde calendar and published it the next year. In the Linde calendar, not only was Liu Chuo's quadratic interpolation with equal intervals applied, but other calculation methods were also improved and perfected. Li Chunfeng's calculation methods were regarded as concise and precise. He also once predicted a solar eclipse.

To meet the needs of mathematical education in the dynasty, Li Chunfeng collated *The Ten Mathematical Classics* and added his commentaries to them with the assistance of Liang Shu, Wang Zhenru, and others. *The Ten Mathematical Classics* exerted great influence on the development of mathematics in China, and even in neighboring countries. Li Chunfeng's commentaries on other works are also of great importance. For instance, some paragraphs he wrote on the *Zhuishu* by **Zu Chongzhi** and his son Zu Geng became the only surviving record of the work after the loss of the *Zhuishu*. Other works by Li Chunfeng include *Dianzhang Wenwu zhi* (A history of cultural geography and dynastic regulations) and *Yisi Zhan* (Divinations of the year *Yisi*).

Deng Kehui

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Liais, Emmanuel-Benjamin

Born **Cherbourg, Manche, France, 15 February 1826**
Died **Cherbourg, Manche, France, 5 March 1900**

Emmanuel Liais was a prolific author, politician, and investigator of diverse astronomical and meteorological phenomena. His personality and idiosyncracies, however, kept him from acquiring a broader reputation within the mainstream astronomical community.

Liais was the third child of Anténor Liais, a prosperous trader from Cherbourg, France, and his wife Mathilde Françoise Dorey. After 1847, Liais began sending astronomical and meteorological observations to the French Academy of Sciences, which drew the attention of Paris Observatory director **Dominique Arago**. In 1854, Liais was one of four astronomers appointed by Arago's successor, **Urbain Le Verrier**. During his tenure there, Liais organized an extensive meteorological telegraphic service and set up a magnetic observatory. His astronomical work was mainly concerned with instrumentation. He developed precise electromagnetically regulated clocks. To try and minimize or eliminate the "personal equation" from observations, Liais conceived, before Carl Braun and Antoine Rédier, the notion of a traveling wire micrometer, or impersonal micrometer, which was not implemented before Johann Adolf (Hans) Repsold's independent fabrication in 1890.

Named director-adjunct of the Paris Observatory in 1857, Liais later clashed with Le Verrier and requested to be sent to Brazil to observe the solar eclipse of 1858. On that occasion, he was among the first to obtain photographs of the phenomenon. Using a polariscope, Liais demonstrated the existence of a "third atmosphere," or corona, around the Sun. For the next 6 years, he remained in Brazil, observing comets and discovering one himself in 1860. Liais produced estimates of the height of the Earth's atmosphere and studied the zodiacal light. He was the first to contest **Edmond Lescarbault**'s purported observation of a hypothetical planet between Mercury and the Sun whose existence had been conjectured by Le Verrier. The following year, Liais demonstrated that the Earth's path had crossed the plane of a comet.

Liais returned to France in 1864 where he published a treatise on astronomical instrumentation as applied to geodesy and navigation, along with a popular book on astronomy, entitled *L'Espace céleste* (1865), which was illustrated by his wife, Margaretta Trouwen van de Kranenbroeck. Liais's idiosyncratic account interwove his voyages of exploration in Brazil with astronomical observations and original findings. Rejected by the Academy of Sciences, Liais went back to Brazil where he was named director of the Imperial Observatory at Rio de Janeiro (1871). Apart from a visit to France to acquire new instruments, he pursued research on comets and planetary motions at the Rio Observatory. Upon retiring from astronomy, Liais returned to Cherbourg and was elected mayor in 1882, a position he held (with a short interruption) until his death.

In his patriotic book on the *Intellectual Supremacy of France*, written in the wake of the Franco–Prussian War, Liais argued against specialization in the sciences. Ever the generalist, he nonetheless produced original work in astronomy and astrophysics as well as in meteorology, physics, geology, and botany. Yet, largely an outsider, Liais failed to acquire the recognition he had yearned for from his colleagues.

David Aubin

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Liddel, Duncan

Flourished **1587**

Scottish mathematician Duncan Liddel was a champion of **Tycho Brahe**'s cosmological model.

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Thoren, Victor E. (1990). *The Lord of Uraniborg: A Biography of Tycho Brahe*. Cambridge: Cambridge University Press.

Lin, Chia Chiao

Born **1916**

Chinese–American astrophysicist Chia Lin worked out the density wave theory for spiral galaxies at the Massachusetts Institute of Technology, together with his student Frank Shu.

Selected Reference

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Lindblad, Bertil

Born **Orebro, Sweden, 26 November 1895**
Died **Stockholm, Sweden, 25 June 1965**

Swedish stellar astronomer Bertil Lindblad published the first quantitative discussion of the Milky Way as a rotating stellar system. He graduated from the Gymnasium in Orebro, where his parents (army officer Birger Lindblad and Sara Waldenstrom) were stationed, and entered the university at Uppsala in 1914, having seen that summer a total solar eclipse from the north of Sweden, directing his interest toward astronomy. Lindblad studied mathematics, physics, and Latin, as well as astronomy, but worked in the laboratory of Allvar Gullstrand (who received the 1911 Nobel Prize in Physiology and Medicine for work on optics of the eye) to support himself, and briefly considered switching to medicine. In fact, he completed a Ph.D. in 1920, having worked with **Östen Bergstrand** on quantitative measurements of the colors of stars and spectroscopic criteria for absolute brightness. After a year and a half at Mount Wilson Observatory and Lick Observatory, Lindblad declined the offer of a permanent position at Harvard College Observatory to return to Uppsala, where he met and married Dagmar Bolin in 1924. They had a daughter and three sons, one of whom, Per Olof Lindblad, recently retired from a distinguished astronomical career.

In 1927, Lindblad was appointed astronomer of the Royal Swedish Academy of Sciences and director of the Stockholm Observatory, where he oversaw the construction of a new facility, in Saltsjobaden, away from the worst of the city lights. Lindblad and his associates in Uppsala and Stockholm were the first to develop quantitative ways of measuring stellar spectral classes, in contrast to the eye estimates from low-resolution spectra epitomized by **Annie Cannon**. Values of integrated intensities of strong, key lines and slopes and discontinuities of the spectral continuum could be calibrated on a few stars of known distance (hence luminosity) to determine the luminosities of many others too far away for direct parallax determination. Giants and supergiants, for instance, have stronger bands of CN (cyanogen) and smaller discontinuities at the edge of the Balmer sequence of hydrogen lines than do dwarf stars like the Sun.

In 1925, Lindblad began considering the implications of a center for the Galaxy as far from the Sun as the 20 kpc measured by **Harlow Shapley** in 1921 and how this might be reconciled with the Sun-centered stellar system of **Jacobus Kapteyn**. He thought in terms of a rotating disk of stars, with those closest to the center moving fastest (just as Mercury orbits the Sun faster than does Pluto). He recognized that such rotation would imply a definite pattern in the sky for motions of stars along the line of sight (radial velocities) and perpendicular to it (proper motions). When **Jan Oort** published observations showing the expected pattern in 1927, he called the paper observational support for Lindblad's hypothesis. Lindblad's own picture of the Galaxy, evolved using methods pioneered by **James Jeans**, had a number of stellar subsystems, with the roundest rotating the most slowly. Modern data confirm the general idea. He also recognized that small excursions ("epicycles") of the motions of the stars around their circular orbits would account for an asymmetry in which stars further than average from their circles appear to lag the average rotation ("asymmetric drift").

In later years, Lindblad attempted to analyze the structure of spiral galaxies in terms of the orbits of stars, including what are now called spiral density waves, which rotate around the galactic centers faster than do the stars themselves, producing spiral patterns that can last much longer than the rotation periods of the galaxies. The details of this process remained unclear to the end of his life and remain so today. Lindblad also studied the growth of interstellar dust grains, especially the phase where a few large molecules clump together to form condensation cores.

Lindblad served as the president of the International Astronomical Union (1948–1952), and immediately thereafter as president of the International Council of Scientific Unions (1952–1955). He was twice elected president of the Swedish Academy of Sciences, chaired the Nobel Foundation in 1965, and was also chairman of the Swedish Natural Science Research Council at the time of his death. Lindblad received a number of honorary degrees and Gold Medals from the Royal Astronomical Society (London) and the Astronomical Society of the Pacific. He on several occasions declined prestigious professorships outside Sweden, giving rise to the folktale of Lindblad's law, that an astronomer ends up living where his wife was born. Along with **Adriaan Blaauw** and others, he was one of the key organizers of the European Southern Observatory and served as president of its council in 1956 and again for a few months before his death.

Suvendra Nath Dutta

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Lindemann, Adolf Friedrich

Born **Langenberg, (Rheinland Pfalz, Germany), 13 May 1846**
Died **England, 25 August 1931**

Adolf Lindemann was an amateur observer who devised an electrometer and other instrumentation, and was a supporter of other astronomers. At the age of 14, he built a telescope with an equatorial mount; he claimed that his proudest moment was when he set a star by its vernier scale and found it exactly on the crosshairs. His early ambition was to be an explorer, but he trained as an engineer and instrumentmaker at Nuremberg, where he continued his astronomical interest by undertaking the reduction of Georg von Neumayer's Australian observations.

Adolf was the father of Frederick Alexander Lindemann, professor of physics and head of the Clarendon Laboratory at Oxford between the wars; this son is better known as Lord Cherwell, friend of Winston Churchill, advisor to the Churchill War Cabinet on science, and head of the British Scientific Intelligence during World War II. Adolf's mistaken title of "professor" likely resulted from the paper in which the Lindemann electrometer first appeared and which Adolf published jointly with his son. Adolf had six other children, two born at Sidmouth, England, the family's main place of residence.

While working for Ertel and Sons in Munich, Lindemann continued his training as an instrument engineer, believing that an ability to make or repair any scientific instrument would be an invaluable skill in his chosen ambition of exploration. He also developed knowledge and skill of surveying, but suffered a severe attack of typhoid fever, leaving him unable to cope with extremes of climate.

Lindemann came to England in about 1870 during the Franco–Prussian War, perhaps because of anti-Semitism, though he maintained his association and interest in his native region and returned there frequently. At Woolwich, Lindemann took a position with Siemens Brothers; in 1874, he became head of the department charged with the responsibility for laying the first transatlantic cable between the United States and Ireland in 1875. In 1872, Lindemann applied for membership of the Royal Astronomical Society and was elected a fellow in 1874. Three of his four sponsors were from the Royal Greenwich Observatory. His astronomical interest and knowledge quickly earned him respect among professional astronomers.

While on a fossil hunting holiday in the Rhineland in 1876, Lindemann accepted a challenge to construct a waterworks to supply the town of Pirmasens, a project that brought him into contact with a banker, Benjamin Davidson. Davidson died a few years later, leaving his wife, Mary, with a family and some fortune; Adolf, a rich man himself, married Mary on 6 May 1884. That year, Lindemann moved from London to Sidholme, Sidmouth in Devon, where he lived until 1928 and where he built a small observatory and workshop.

Lindemann surveyed several potential sites in Europe for building astronomical observatories. He met **Maximilian Wolf** and assisted him in the choice of a site for the Königstuhl Observatory at Heidelberg. Wolf visited Lindemann at Sidmouth in 1896 and stayed with them at Sidholme; such was their friendship that Lindemann left money to Wolf in his will.

Lindemann spent much of his time at Sidmouth building and perfecting accessories for his observatory's instruments. He devised an ingenious chronograph and a revolving eyepiece that found application in many other observatories. Each ocular of the eyepiece was electrically heated to overcome condensation and came automatically into the focus position. Throughout the Sidmouth years, Lindemann spent considerable time and effort perfecting a telescope design similar to the coudé pattern that was evolving independently and simultaneously. Lindemann's telescope featured two plane mirrors, inclined at 45° to the polar axis, that could be rotated in right ascension and declination, enabling the light to be reflected down the polar axis. The fixed telescope was excellent for photography and experiments in spectroscopy and photometry; similar techniques are applied in coelostat (two mirror) and siderostat (single mirror) instruments.

In 1915, Lindemann published a paper showing how to photograph bright stars in broad daylight by placing a target star in the center of the telescope's field and excluding as much sky light as possible with an iris diaphragm. An electrically timed shutter determined the period that the cell was exposed to the stellar light and during which a Lindemann electrometer received charge. He invented this electrometer, a derivative of the quadrant electrometer; it featured a glass fiber needle, coated with platinum about 30 microns thick, suspended at the center of a silica torsion thread 3 microns thick and attached at each end to a silica frame that kept it under tension. The needle was suspended so that it could deflect between the quadrant plates which were kept at a fixed electric potential. The glass fiber needle was carefully balanced so that the zero point and sensitivity of the instrument was independent of its position or tilt. Because the whole instrument was very lightweight, it could be placed in the position of his telescope's eyepiece. The Lindemann electrometer became a portable physics instrument, its design discussed in many standard electricity textbooks prior to the electronic age. All of Lindemann's pieces of apparatus were made by his own hands in the Sidholme workshop.

As late as June 1931, Lindemann visited the Royal Greenwich Observatory to enquire if and how the Earth's magnetic variations might affect the timekeeping of metal-compensated and invar steel pendula.

Johann Palisa at the Vienna Observatory discovered two minor planets on 29 August 1916; he named one of them for Lindemann, the other after Max Wolf. His original citation for these planets, in translation, reads: "Planet 828 I dedicate to Herr Lindemann, who unselfishly and generously supports astronomical research."

Gerald White and *Christof A. Plicht*

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Lindsay, Eric Mervyn

Born **Portadown, (Northern Ireland), 26 January 1907**
Died **Armagh, Northern Ireland, 27 July 1974**

Eric Lindsay, one-time director of the Armagh Observatory, Northern Ireland, was a great popularizer of astronomy in his native land, a persuasive proponent of international collaboration in astronomy, and a gifted observational and theoretical researcher.

Lindsay was the seventh and youngest son of Richard and Susan Lindsay. He was schooled at the King's Hospital School, Dublin, before graduating from Queen's University, Belfast, in 1928. He continued his studies at Harvard University under **Harlow Shapley**, who remained one of Lindsay's closest friends throughout his life. After gaining his Ph.D. in 1934 he became the senior assistant at the Boyden Observatory near Bloemfontein, South Africa. Linday married Sylvia Mussells, formerly as assistant astronomer at Harvard, in South Africa in 1935.

Much of Lindsay's observational work in South Africa concerned the Magellanic Clouds, and these were to remain his chief area of interest throughout his research career. His pioneering studies of star clusters in the Magellanic Clouds produced remarkably complete and authoritative catalogs of these important objects. Lindsay also studied variable stars, emission-line objects, and diffuse nebulae in these neighboring galaxies.

On the death of **William Ellison** in 1936, the directorship of Armagh Observatory, close to Lindsay's hometown, became vacant, and Lindsay was faced with the possibility of returning to Northern Ireland. When his old research advisers at Harvard University, Shapley and **Bart Bok**, heard that Lindsay was considering the directorship at Armagh, one was heard to remark "That fool, Lindsay, has gone and ruined himself." But Lindsay was, in fact, to create for himself a successful career in Ireland and in the process completely revitalize both Armagh Observatory and Irish astronomy in general.

The situation at Armagh prior to Lindsay's arrival was dire; there were no serviceable astronomical instruments or staff, and funds were almost nonexistent. Always a shrewd and perceptive man, Lindsay realized that for the observatory to survive, involvement in major international projects was essential. He thus began strengthening the practical cooperation with the Boyden Observatory that was to remain an important part of Armagh's work. Lindsay secured the support of the Northern Ireland government and brought the distinguished Estonian astronomer, **Ernst Öpik**, from Harvard in 1947. Öpik became Lindsay's successor as director of Armagh and edited the *Irish Astronomical Journal* from there for many years. The observatory's fortunes advanced and, after many years of perseverance and persuasion, the Armagh–Dunsink–Harvard Telescope was set up at Boyden, widely regarded as one of the first examples of a collaborative international observatory. Lindsay formed many valuable associations during his promotion of Irish astronomy, among them Eamon de Valera, former Prime Minister and President of Ireland, who had himself studied mathematical physics and retained an interest in science.

Lindsay was awarded an OBE in 1963.

Alastair G. Gunn

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Shapley, H. and E. M. Lindsay (1963). "A Catalogue of Clusters in the Large Magellanic Cloud." *Irish Astronomical Journal* 6: 74–91.

Lipsky, Yuri Naumovich

Born **Dubrovno near Vitebsk, (Belarus), 22 November 1909**
Died **Moscow, (Russia), 24 January 1978**

Yuri Lipsky was a Soviet astrophysicist who specialized in the field of lunar studies and selenography. During the late 1950s and early 1960s, he became the principal interpreter of the first photographs of the Moon's farside.

Lipsky began his adult life as an industrial worker. He was both a graduate (1938) and post-graduate of Moscow University, where he came under the influence of **Vasilii Fesenkov**. Lipsky also served in the Soviet defense against Germany's invasion during World War II. By 1963, he was appointed chief of the Physics of the Moon and Planets Department at the Sternberg State Astronomical Institute of Moscow University. His personal bibliography is not very vast, and not all of his scientific results were confirmed over the course of time.

Lipsky's reputation arose in connection with his interpretation of the first photographs of the farside of the Moon, which revealed the surprising *absence* of lunar maria as compared to its nearside. Lipsky maintained close contacts with Sergei Pavlovich Korolev, the chief designer of Soviet cosmonautics. Lipsky analyzed the photographs from the Luna-3 spacecraft flyby made in 1959 and from the Zond-3 flyby made in 1965. In the style of that period, he was the driving force behind a politically motivated endeavor to name landscape features on the lunar farside. Under his *aegis*, the first full globes of the Moon's surface and a number of selenographic maps were composed in the USSR. A crater on the farside has been named for him.

Alexander A. Gurshtein

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Littrow [Littroff], Johann Joseph (Edler) von

Born **Bischofteinitz, (Czech Republic), 11 March 1781**
Died **Vienna, (Austria), 30 November 1840**

Johann von Littrow was an observatory director and one of the first astronomers to recognize the existence of the solar chromosphere. Born into a German-speaking family, he entered the University of Prague in 1802. After wide-ranging studies, Littrow took a post as tutor in Vienna. There he came under the influence of J. Hall, the director of the Realschule, which led to his study of astronomy. In 1807, Littrow assumed the professorship of astronomy at the University of Cracow after the Austrians occupied that part of Poland. At this time he changed his family name from Littroff. Littrow married Karoline von Ullrichsthal; they had five sons, one of whom, **Karl von Littrow**, would succeed his father in Vienna 2 years after his father's death.

Littrow moved to Kazan in 1809 to direct the observatory there. He became a corresponding member of the Russian Academy of Sciences in 1813. In 1816, he became codirector of the Ofen Observatory in Buda (modern Budapest). In 1819, Littrow was appointed director of the Vienna Observatory and professor of astronomy at Vienna University. He also held the chair of higher mathematics at the university from 1834 to 1837.

Littrow's astronomical work was collected in his *Theoretische und practische Astronomie* (Theoretical and practical astronomy, 3 Vols., 1821–1827). He also wrote on algebra, geometry, chronometry, physics, and optics. His *Dioptrik, oder Anleitung zur Verfertigung der Fernröhre* (Dioptrics, or guide to the manufacture of telescopes, 1830) was a general survey of optics with a focus on telescope making. In 1839, Littrow's *Atlas des gestirnten Himmels* (Atlas of the starry heavens) appeared in Stuttgart for professionals employing **Johann Bode**'s constellations.

Littrow was a noted popular writer. His 1825 *Populären Astronomie* (Popular astronomy) was widely read. (Geneticist Gregor Mendel was influenced by it.) From 1834 to 1837, Littrow's enormously successful four-volume *Die Wunder des Himmels* (The wonders of the heavens) appeared, selling some 10,000 copies. He is said to have devised a scheme to signal intelligent life on other planets by building large canals in geometric patterns, filling them with water and oil, and lighting them at night.

Littrow was knighted by Emperor Franz Josef II. The lunar crater Littrow is named for him.

Richard A. Jarrell

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Günther, S. (1884). "Littrow: Johann Joseph v." *Allgemeine Deutsche Biographie*. Vol 19, pp. 1–2. Leipzig: Duncker and Humblot.

Littrow, Karl Ludwig von

Born **Kazan, Russia, 18 July 1811**
Died **Vienna, (Austria), 16 November 1877**

Karl von Littrow was the son of **Joseph von Littrow**. He became an assistant to his father at the Vienna Observatory in 1831. Littrow specialized in the study of asteroids, and computed the orbits of the more important of these. He also computed the orbits of comets. In 1842 he succeeded his father as director of the Vienna Observatory.

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Liu Zhuo [Ch'o]

Born **China, 544**
Died **China, 610**

Liu Zhuo produced the *huang-chi-li* (or *huang ji*; *circa* 600), the imperial calendar of the Sui dynasty. In his data analysis he used a form of quadratic interpolation.

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Lobachevsky, Nikolai Ivanovich

Born **Nizhni Novgorod, Russia, 20 November/2 December 1792**
Died **Kazan, Russia, 12/24 February 1856**

Nikolai Lobachevsky is remembered as one of the founders of non-Euclidean geometry. Although he was born into a poor family (made even poorer by the death of his father when he was seven), Lobachevsky's mother ensured that he received a good education. In 1802, he entered the Gymnasium in Kazan, a city on the confluence of the Kazanka and Volga rivers, in Tatarstan, Russia. Lobachevsky remained at the school until 1806; in the following year he gained admission to the recently founded Kazan University (1805). There, he was much influenced by the German mathematician, Johann Martin Bartels, a former teacher of **Carl Gauss**. By 1812, Lobachevsky was awarded his master's degree in physics and mathematics. In succession, he was appointed an extraordinary professor of mathematics in the university (1814), an ordinary professor (1822), and, in 1827, to the rectorship in Kazan, a position he held until 1846. In 1832, Lobachevsky married Varvara Aleksivna Moisieva; the couple had seven children.

Lobachevsky became interested in the problem of the parallel postulate in Euclidean geometry, a problem that had long taxed the finest mathematical minds in Europe. In his early years, he does not seem to have deviated from the standard geometrical thinking of those days but, in February 1826, Lobachevsky read a paper, "Exposition succincte des principes de la géométrie," to the Department of Physical and Mathematical Sciences at Kazan. This appears to have been the first public disclosure of non-Euclidean geometry and, with it, the solution to the parallel postulate problem. Roughly speaking, this problem can be explained two-dimensionally as follows: The axioms of Euclidean geometry can be arranged in such a way that by assuming up to, but not including, the last axiom (the parallel postulate), one can show that, given any line L and point P not on L, there exists at least one line through P parallel to L. It can then be shown that there are actually two (and only two) possibilities: Either there is a unique such line (which, if taken as the final axiom, produces Euclidean geometry) or else there are infinitely many such lines. If this latter possibility is considered, then the non-Euclidean geometry discovered by Lobachevsky results. The elegant axiomatic formulation of geometry referred to here is essentially that of the German mathematician, David Hilbert, who clarified this issue at the end of the 19th century.

In 1829, Lobachevsky published an extended version of that paper in the *Kazanski vestnik* (*Kazan Messenger*), under the title, "On the Principles of Geometry." This paper also considered the physical geometry of space (*i.e.*, whether it was Euclidean or non-Euclidean). Independently of Lobachevsky, a young Hungarian mathematician, Jànos Bolyai, had arrived at similar conclusions but hesitated in publishing them. When Bolyai did publish his results (in an appendix to the book, *Tentamen* [1831], written by his father Wolfgang), Lobachevsky's paper had been in print for 2 years. In any case, the mathematician, Gauss, had explored related possibilities even earlier but never published his findings.

The firm rootedness of Euclidean geometry, together with the abstractions inherent in the new geometry, meant that, at first, little attention was paid to the work of Lobachevsky and Bolyai. However, the rather elegant formulations of this geometry later given by **Felix Klein** and **Jules Poincaré** helped its recognition by giving it some intuitive appeal. Further understanding of non-Euclidean geometry arose from the work of Georg Friedrich Bernhard Riemann (1866), who generalized the foundations of geometry and initiated the study of differential (or Riemannian) geometry. The final link in this chain was then provided by the axiomatic treatment of geometry given by Hilbert (as mentioned earlier).

In 1916, **Albert Einstein**'s general theory of relativity, the most successful theory of gravity to date, took Riemannian geometry as its mathematical basis. In this sense, Lobachevsky (and Bolyai) were very important players in the development of modern physics and, indeed, in modern astronomy, since the initial (and successful) tests of Einstein's theory were essentially astronomical in nature. One of these tests resolved the long-standing problem associated with the orbit of the planet Mercury. Another involved the deflection of starlight at the edge of the Sun, and this was then witnessed during a total solar eclipse. The great English geometer, William Kingdon Clifford, called Lobachevsky the "Copernicus of Geometry."

During his lifetime, Lobachevsky achieved many more things than just success in geometry. He reorganized the library and museum facilities in Kazan and was a major force in rebuilding the university after its disastrous fire of 1842. In that same year, he was elected to the Göttingen Gesellschaft der Wissenschaften for his work on non-Euclidean geometry. Strangely, and without explanation, he was removed from his professorship and rectorship in 1846. Toward the end of his life, Lobachevsky became blind; his last work, *Pangéométry*, had to be dictated to a scribe.

Graham Hall

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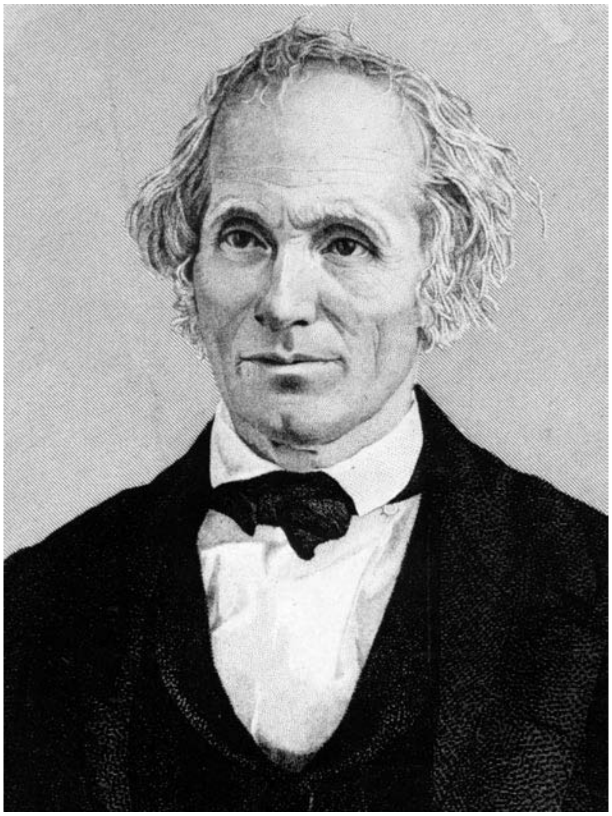
Locanthi, Dorothy N.

➔ **Davis Locanthi, Dorothy N.**

Locke, John

Born **1792**
Died **1856**



John Locke was an American physician who ran a girls' school in Cincinnati, Ohio. He discovered the Perseid meteor shower.

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Lockyer, Joseph Norman

Born **Rugby, Warwickshire, England, 17 May 1836**
Died **Sidmouth, Devon, England, 16 August 1920**

Sir Norman Lockyer was a talented solar observer who used the newly invented spectroscope to examine the properties of the Sun's component parts. Lockyer is remembered for the discovery of helium in the solar spectrum (later found on the Earth) and as the founding editor of the prestigious journal *Nature*. He was born to Joseph Hooley Lockyer, a pharmacist and founder of Rugby's literary and scientific society, and to Anne Norman. He was educated in private schools in Kenilworth, Warwickshire, and Weston-super-Mare, Somerset, and later studied in Switzerland and France, before joining the British War Office. In 1858, Lockyer married Winifred James, with whom he had nine children before she died in 1879. In 1903, he married Thomazine Mary Browne, who lived until 1943.

In 1858, Lockyer observed an eclipse of the Sun, his first recorded interest in solar observation. Lockyer came to astronomy just when the spectroscope became available. Others used spectroscopy to investigate stellar spectra, but Lockyer took up the technically trickier task of obtaining spectra from different portions of the solar disk.

During the 1850s and 1860s, astronomers debated whether the features seen during total eclipses – the soft white glow of the corona and the fiery red prominences – belonged to the Sun or to the Moon. Lockyer's first major scientific discovery, in 1868, was his achieving separate spectra for the prominences and chromosphere when the Sun was not eclipsed, indicating that these belonged to the Sun. Remarkably, the French Academy of Sciences received notification of the observation of prominence spectra from two separate scientists at the same meeting, Lockyer and the distinguished French observer **Jules Janssen**. There was no unseemly squabble over precedence, and the French government struck a medal commemorating both men.

In the laboratory, Lockyer and his assistants reproduced most of the lines observed in the solar spectrum, but one particularly bright line, classified D_3, remained unidentified. Around 1869, Lockyer made the bold suggestion that the D_3 line was formed by an element not found on the Earth. He named it helium after "helios," Greek for Sun. Helium did indeed turn out to be a new element, the next lightest after hydrogen, and the second most abundant in the Universe.

The best way to obtain spectra of the outer atmosphere of the Sun is to blank out the visible disk, the photosphere; to do that properly required a total solar eclipse. For 35 years, Lockyer (latterly with his son, Jim) attended a remarkable series of solar eclipses in Sicily (1870), Ceylon (1871), America (1878), Egypt (1882), Grenada (1886), Lapland (1896), India (1898), Spain (1900), and Majorca (1905).

Lockyer was keen to bring his discoveries to a wider audience. He was an excellent public speaker, delivering talks to enthusiastic audiences all over Britain. Lockyer contributed articles on science to *The Reader*, a popular journal; when it folded, he launched a new journal, *Nature*, dedicated entirely to the natural sciences in 1869. It quickly moved from a journal of exposition to one of original research, and is now one of the most important research journals in the world.

During the 1870s, Lockyer was secretary to the Devonshire Royal Commission, which overhauled the teaching of science in Britain. One of its major achievements was the establishment of the South Kensington campus in London, now home to Imperial College and the Science and Natural History Museums. Here, Lockyer also founded a solar observatory.

In 1887, Lockyer published *The Chemistry of the Sun*, which put forward a radical new theory, "the dissociation hypothesis." Its details have been found wanting, but the heart of the theory remains valid: Within the Sun, atoms become ionized, splitting off their outer electrons into a sea of particles or plasma.

Likewise, the other great theory Lockyer championed, the meteoritic hypothesis, has now been superseded. He believed that much of the Universe's structure resulted from meteoritic bombardment, *i. e.*, that comets, asteroids, and even planets were formed by the accumulation of meteoritic debris. This is not far from current theories of formation for the smaller bodies of the Solar System, but Lockyer argued that this hypothesis explained the evolution of stars along a sequence of stellar types and even the formation of spiral galaxies such as the Andromeda nebula. On both counts, he was completely mistaken. His scenario for the formation and evolution of stars was, though, a precursor of the giant-and-dwarf theory of **Henry Norris Russell**.

In 1883, there was a series of spectacular sunsets. Lockyer analyzed their spectra and attributed them to dust from the explosion of Krakatoa. Lockyer asserted that volcanic and meteorological events on Earth were driven by the solar cycle. Lockyer and his son produced a body of work correlating weather patterns around the world with solar behavior; the Lockyers' painstaking observations helped establish meteorology as a predictive science.

On holiday in Greece in 1890, Lockyer wondered if there was any astronomical significance to the alignment of Greek temples. Subsequent holidays saw him visiting the pyramids, Stonehenge, and stone circles around Britain. Lockyer was perhaps the first person to systematically investigate astronomical alignments for ancient monuments; his resulting *Dawn of Astronomy* was a seminal work for archeaoastronomy.

In his later years, Lockyer continued to steer the direction of British science, taking on the presidency of the British Association, and founding the British Science Guild (1904), a forum for debate on science policy. In his 70s, when authorities proposed relocating the solar observatory from South Kensington, Lockyer believed that the proposed site in Cambridge was too close to the city lights, and resolved to found his own observatory. The Norman Lockyer Observatory, at Sidmouth in Devon, first opened in 1912 but soon shut because of World War I, and did not open fully until 1919. After Lockyer's death, the observatory came under the stewardship of Jim Lockyer. Astronomical research continued until 1961, geophysical research until 1980. The Norman Lockyer Observatory Society currently runs the site as an educational establishment.

Lockyer received many awards, including the 1874 Rumford Medal from the Royal Society and the 1875 Janssen Medal from the French government, as well as honorary degrees: Hon LLD from the universities of Glasgow, Edinburgh, and Aberdeen, Hon Sc.D. from the Universities of Cambridge and Sheffield, and an Hon D. Sc. from Oxford University. He was elected a fellow of the Royal Society in 1869, named the Rede Lecturer at Cambridge in 1871, and created a Knight Commander of the Order of the Bath [KCB] in 1897. In 1903/1904, Lockyer served as the president of the British Association.

Michael Frost

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Lodge, Oliver Joseph

Born **Penkhull near Stoke-on-Trent, England, 12 June 1851**
Died **Lake near Salisbury, England, 22 August 1940**

British physicist Oliver Lodge touches on astronomy primarily through his discussions around 1919 of the significance of the gravitational deflection of light – see **Arthur Eddington** – and the possibility of gravitational lensing of one star by another. Lodge was the eldest of nine children of a wealthy supplier of materials for the pottery industry. After grammar school, he entered the family

business, but found it less than congenial, and used periodic visits to London to hear the lectures of John Tyndall (1820–1893) and others at the Royal Institution. Lodge resumed his education in about 1872, and received a D.Sc. from University College London in 1877. His early publications touched on electricity, magnetism, and other standard topics in physics.

Lodge began teaching physics at Bedford College for Women and University College London. He was appointed professor of mathematics and physics in 1881 at the new University College, Liverpool, and principal of the University of Birmingham (also new) in 1900, from which he retired in 1919. He and his wife, *née* Mary Marshall, had 12 children.

The most important of Lodge's scientific contributions were made from Liverpool, particularly to the theory of the ether and to propagation of electromagnetic fields. He was able to show that the (then widely accepted) ether could not be carried along by moving bodies, and this can be seen as a step toward **Albert Einstein**'s theory of special relativity. He is remembered for his lecture commemorating the early death of Heinrich Hertz (1857–1894) held at the Royal Institution in London in June 1894. Lodge stressed the experimental aspects of Hertz's work on electromagnetic waves. Lodge himself introduced the idea of a coherer as a detector of waves, an improvement over Hertz's resonator, and it helped to lead Guglielmo Marconi (1874–1937) of Italy and Aleksandr Popov (1859–1906) of Russia to the development of wireless telegraphy.

After about 1900, Lodge was engaged primarily in organizational activities and popularization of science. He also became interested in psychic research, including telepathy and telekinesis and the possibility of communicating with the spirits of the dead (partly in association with Arthur Conan Doyle, author of the Sherlock Holmes stories). Lodge received among many other honors the Rumford Medal of the Royal Society of London (1898) and the Faraday Medal of the Institution of Electrical Engineers (1932). He was knighted in 1902, and there were many years when every volume of *Nature* contained at least a note from him on topics of current interest in physics.

Horst Kant

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Lohrmann, Wilhelm Gotthelf

Born **Dresden, (Germany), 31 January 1796**
Died **Dresden, (Germany), 20 February 1840**

Wilhelm Lohrmann's profession as a cartographer had a strong, positive influence on his avocation as an amateur astronomer and selenographer. His parents, Wilhelm Gotthelf Lohrmann and Sophie Michaelis, were brickmakers. Lohrmann attended the garrison school between 1802 and 1810 and then, until 1814, the construction school at the Dresden Arts Academy. In 1815 he joined the survey office, which was founded to supply charts for the tax office, and was appointed head of the lithographic printing office in 1823. In this position Lohrmann prepared the topographic data for the maps that were printed and published as the *Geognostische Specialkarte des Königreiches Sachsen* between 1836 and 1845.

When, in 1828 the new technological education institute was opened, a predecessor to the college, Lohrmann was appointed director. The same year he also took over the responsibility for the Königlich Mathematisch–Physikalischer Salon (Royal Mathematical–Physical Collection). In this position Lohrmann erected a small astronomical observatory and defined the local meridian by setting up pillars near Rähnitz-Hellerau and Rippchen near Dresden.

Lohrmann had begun astronomical observations from his home in 1821. His main interest was the topography of the Moon, and he published four parts of his *Topographie der sichtbaren Mondoberfläche* (Topography of the visible lunar surface) as early as 1824. This work was completed in 1836 and followed by his *Kleine Karte des Mondes* (Small map of the Moon) with a diameter of 38.5 cm (15–1/16 in). A larger map based on Lohrmann's work was published in 1878 (38 years after his death) by **Johann Schmidt** and republished by Paul Ahnert in 1963. This work was highly commended by **Simon Newcomb** and influenced **Wilhelm Beer** and **Johann von Mädler** and their *Mappa selenographica*. Schmidt also used much of Lohrmann's data and drawings for his book *Der Mond* (*The Moon*), published in 1856. Further works by Lohrmann were *Das Planetensystem der Sonne* (Dresden, 1822), *Meteorologische Beobachtungen* (1831–1833), and an article on meteorites in Ludwig Gilbert's *Annalen der Physik* in 1823.

Lohrmann was married twice, in 1819 to Christiane Amalie, daughter of the master baker Seifert, and in 1828 to Henriette, daughter of professor Dr. C. E. Raschig, a military surgeon of the general staff. With his first wife he had four sons and two daughters, with his second wife three sons and one daughter. He died of typhoid fever. He is honored by the minor planet (4680) Lohrmann and a lunar crater.

Christof A. Pflicht

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Lohse, Wilhelm Oswald

Born **Leipzig, (Germany), 13 February 1845**
Died **Potsdam, Germany, 14 May 1915**

German observational astronomer Wilhelm Lohse founded the archive of astronomical photographic plates at Potsdam Observatory, one of the oldest in the world. Lohse graduated in the natural sciences (particularly chemistry) from Leipzig University. In 1870, he began work at F. von Bulow's private observatory at Bothkamp, Germany under **Hermann Vogel**. Their work in spectral analysis established Bothkamp as a major astrophysical facility. With the founding of the government-supported Potsdam Observatory in the 1870s, Lohse moved there with the position of *hauptobservator* (head observer) under Vogel's directorship. He continued to observe there until near the end of his life and established the Potsdam plate archives, illustrating the value of photography to traditional astronomical work. It vies with the archives at Harvard College Observatory for the oldest collection of useful plates (though Harvard has daguerreotypes of the Moon dating from the early 1850s). The Potsdam collection was partly destroyed during World War II.

Milcho Tsvetkov

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Lomonosov, Mikhail Vasilievich

Born **Denisovka, (Lomonosovo), Russia, 8 November 1711**
Died **Saint Petersburg, Russia, 15 April 1765**

The first Russian scientist–educator–poet–innovator, Mikhail Lomonosov left an appreciable trace in all the sciences of the 18th century. His works on astronomy, physics, chemistry, engineering, history, economy, geology, geography, and literature for a long time determined how these arts and sciences would develop in Russia.

Lomonosov was born in a family of well-to-do peasant fisherman in the north of Russia. His village was near the coast of the White Sea at a latitude of 64°. Lomonosov's father constructed a perfectly equipped galiot, on which his son and he sailed the Arctic Ocean up to a latitude of 70°. Mikail should have continued in his father's trade as the fisherman's sole successor. However, at age 19, Lomonosov stealthily left his father's house for Moscow, to receive an education. Hiding his country origin, he studied in Moscow, then in Saint Petersburg, and finished his education in Germany, at the universities of Marburg and Freiberg.

In 1745 Lomonosov became a professor at the Saint Petersburg Academy of Sciences – the first Russian, as the other scientists in the academy had been invited from abroad. In 1756 some land was granted to Lomonosov, at the center of Saint Petersburg, where he built a house that included a mosaic workshop and chemical laboratory.

Lomonosov was married (1740) to a German woman, with whom he became acquainted during his studies in Germany. The couple had one daughter.

Lomonosov had a quick temper that worked against him in court intrigue. Later the great Russian poet Aleksandr Pushkin, who admired the scientist, wrote: "I as Lomonosov do not want to be a buffoon even for the Lord."

Lomonosov engaged in astronomical and optical research during the last years of his life, while already a mature scientist. He is responsible for much of the Russian astronomical terminology.

In optics Lomonosov designed (1760/1761) a telescope employing a siderostat. The main tube sat motionless, pointed in a horizontal direction, and starlight was directed into it with the help of a flat, rotating mirror. Otherwise, such telescopes entered into use only in the second half of the 19th century.

In 1762 Lomonosov offered a new reflector design in which the main mirror is slightly inclined to the axis of a tube (by, *e. g.*, 4°). The secondary flat mirror is absent (or is off-axis) in this scheme. Independently of Lomonosov the idea was put to use by **William Herschel** in 1789.

Lomonosov was also engaged in development of a "night visual tube," the purpose of which was to allow an observer to more distinctly see a target under weak illumination. This tube looked similar to a normal telescope, and his contemporaries did not recognize anything new in it. The principles of its action were formulated only in the 20th century as new discoveries were made in the physiology of sight. Among other Lomonosov inventions appear the refractometer, an incendiary tool consisting of mirrors and lenses; seaworthy instruments; and other optical devices. Unfortunately, even the drawings of some of these were not kept.

Lomonosov studied the figures of objective mirrors using a test with an aperture mask that was likely similar to the more sophisticated Hartmann test. He was the first in Russia to develop photometric methods, by improving **Christiaan Huygens**'s device (described in *Cosmotheoros*, 1698) and by carrying out measurements with it during a solar eclipse.

In astronomy, Lomonosov put forward an original theory of a comet's structure in which electricity forces luminescence in the comet's tail. In 1761, he observed the transit of Venus from his home observatory. Lomonosov described details of this phenomenon in "The Appearance of Venus on the Sun …." He interpreted the turbidity of the solar disk's edge at first contact, and the formation of a luminous "blister" at third contact, as being the result of the presence of an atmosphere surrounding the planet. This work was published in Russian and German, but remained almost unnoticed. In 1769 a similar explanation of the phenomenon was given by English astronomer **Nevil Maskelyne**, and later such a conclusion came from other astronomers as well, *e. g.*, **Johann Schröter** and Herschel. Lomonosov was a strong supporter of ideas about the plurality of inhabited worlds.

In other, related fields, Lomonosov (in a 1748 letter to **Leonhard Euler)** formulated a law of conservation of mass and verified it by experiments on the oxidation of metals. (The results of these experiments were confirmed in 1773 by the French chemist Antoine-Laurent Lavoisier.) He also gave much attention to the study of gravitation with the help of special pendula and other devices.

Lomonosov's role as popularizer and organizer of science was huge. For example, he described many difficult scientific phenomena in poetic form. With amazing insight Lomonosov thus described processes occurring in the Sun, ones proven by astrophysicists more than 100 years later:

Tam ognenny valy stremiatsa
I ne nahodjat beregov,
Tam vihri plamenny krutjatsa
Borjusshis' mnozhestvo vekov:
Tam kamni, kak voda, kipjat,
Gorjasshi tam dozhdi shumjat.

Lomonosov helped found (1755) the Moscow University that nowadays carries his name. In 1956 presidiums of the USSR Academy of Sciences established the Lomonosov Gold Medal, which was presented for outstanding works in the natural sciences. His name appears on maps of the Moon and Mars.

Sergei Maslikov

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Longomontanus

➔ **Severin, Christian**

Loomis, Elias

Born **Willington, Connecticut, USA, 7 August 1811**
Died **New Haven, Connecticut, USA, 15 August 1889**

As an astronomer, Elias Loomis was recognized primarily as an educator. He wrote numerous textbooks on astronomy and mathematics. However, his contributions to original astronomical research were comparatively minor, whereas in meteorology he played an impressive role, devoting the last 20 years of his life mainly to meteorology.

Loomis, the eldest son of the Reverend Hubbell and his wife Jerusha (*née* Burt) Loomis, was a descendent of Joseph Loomis, who came from England in 1638 and settled in Windsor, Connecticut in 1639. At an early age Loomis displayed excellent linguistic skills, having read the New Testament in its original Greek. He was admitted to Yale at age 14, but because of frail health did not actually begin attending classes for another year. After graduating in 1830, Loomis taught mathematics for a year and a half at Mount Hope Institute in Baltimore, and then entered Andover Theological Seminary in expectation of becoming a minister. At Andover he was the most proficient scholar in Hebrew. But in 1833 Loomis was appointed a tutor at Yale, where for a year he chose to teach Latin.

After the spectacular return of the Leonid meteor shower in 1833, Loomis switched his major interest from linguistics to astronomy, becoming **Denison Olmsted**'s assistant. In October 1834, Loomis presented a paper at the Connecticut Academy of Arts and Sciences on **Ernst Chladni**'s specifications on how to determine the heights of meteors from observations at two widely separated stations, and the successful results obtained by **Heinrich Brandes** and **Johann Benzenberg** on the meteors of 1798. Loomis then contacted professor Alexander Catlin Twining (1801–1884) of the United States Military Academy, West Point, New York with plans for him to observe the Leonids of 1834 from New Haven, and Twining from West Point. Their results were described by **Hubert Newton** as "only marginally successful," but theirs were the first such observations undertaken in America.

Loomis and Olmsted were the first in America to recover comet 1P/1835 P1 (Halley). With the slow international communication in those days, they were unaware that some 25 days earlier Étienne Dumouchel (1773–1840) in Italy had already spotted the comet.

In the spring of 1836 Loomis was called to Western Reserve College in Ohio as chairman of mathematics and natural philosophy. A condition of his acceptance was that he be allowed to spend a year in Europe studying and acquiring the necessary telescopes and clocks to equip a small observatory. Loomis spent the rest of 1836 and most of 1837 in Paris attending the lectures of **Jean Biot**, **Simeon Poisson**, and **Dominique Arago** among others.

In London, Loomis acquired a 4-in. Simms equatorial refractor, a 3-in. Simms transit circle, and a clock with a mercurial pendulum by Molineaux. On arriving at Western Reserve in Hudson, Ohio, Loomis supervised the construction of one of the first permanent observatories to be established in the United States. In his address at the dedication of the observatory, Loomis decried the lack of astronomical observatories in the United States, an issue frequently repeated by him and others. When not teaching classes, Loomis devoted most of his time to careful determination of the latitude and longitude of the observatory. In those early days of expansion to the West, the Western Reserve observatory provided a vital benchmark for the mapping of the United States west of the Appalachian Mountains.

In 1844 Loomis was offered a professorship at the University of New York. There he undertook writing a successful series of mathematics texts as well as one of his better-known treatises, *The Recent Progress of Astronomy, Especially in The United States*, and an expanded version of *Recent Progress* in 1856. Loomis's survey of American observatories was also published in expanded form in *Harper's New Monthly Magazine* over several issues. Some of the observatories described have passed out of existence with little documentation other than the Loomis articles.

In 1860 Loomis was finally appointed as Olmsted's successor at Yale. By that time he had published his *Treatise on Astronomy*, and a few papers on meteors, comets, and sunspots, but his interests had shifted mainly to other fields, especially meteorology, the Earth's magnetic field, and the aurorae. He was the first to prepare a map of the frequency distribution of the aurorae.

A compilation by Newton of the publications of Loomis gives 164 titles, including 26 full length treatises: five in astronomy, 15 in mathematics, one in meteorology, one on astronomy and meteorology, three on Loomis genealogy, and one on natural philosophy (now called physics). His textbooks in mathematics cover the entire range from arithmetic for children through advanced calculus and analytic geometry for college students. Some 600,000 copies of his astronomy and mathematics treatises were sold, providing him a substantial income.

The research papers on astronomy that Loomis published dealt mainly with objects in the Solar System, especially early observations of meteors and comets. Apart from what was included in his treatises, Loomis wrote only three papers on stars. They included a comparison of two star catalogs in 1854, a study of the eclipsing variable Algol, for which he correctly concluded that the period is not constant, and a suggested new period for the peculiar variable η Carinae. **Rudolf Wolf** had determined a period of 46 days based on two early observations in 1677 and 1751, followed between 1815 and 1861 by what appears to be a partial cycle around maximum. Loomis, using exactly the same data, derived a period of 76 days, declaring Wolf's period erroneous. Actually both periods do satisfy the given data but later observations confirmed neither.

Loomis was a pioneer in the study of terrestrial magnetism. As early as 1836 he made observations at Yale on the variation of the magnetic needle. In 1870 he published an important paper relating terrestrial magnetism and aurorae to sunspot activity.

The aurora borealis was exceptionally bright as seen from New Haven on 28 August 1859 and remained bright each night until 4 September 1859. Loomis was intrigued and collected observations from Europe, Asia, and the Southern Hemisphere. He then compiled as much material as possible on previous brilliant displays. From his analyses Loomis concluded that when there are brilliant displays in the Northern Hemisphere there are simultaneously displays in the Southern Hemisphere. The lower heights of the displays he found to be about 50 miles above the Earth while streamers reached upward to 150 miles.

After 1869, Loomis published no research papers specifically on topics in astronomy. Instead, he spent 20 additional years on meteorology, and it is in that science that he made his most important original contributions. As early as 1837 he published hourly meteorological observations, stimulated by two then prevalent contradictory theories of storms. By 1846 Loomis had developed a unique system of data collection and analysis and published the first synoptic weather map. This new technique of presenting weather information exerted a profound influence on meteorology in the following decades during which the competing theories of storms were resolved. His mapping technique formed the basis for weather forecasting. After returning to Yale in 1860 Loomis compiled meteorological data for New Haven and surroundings, spanning 86 years. In 1871 the United States Signal Service was established, providing daily weather maps according to the plans Loomis had envisioned 30 years before. Loomiss' final paper in a series called *Contributions to Meteorology,* was printed by the National Academy of Sciences in 1889.

Loomis was a member of the National Academy of Sciences, the American Philosophical Society, and the American Academy of Arts and Sciences, and an honorary member of the Philosophical Society of Glasgow, the Royal Irish Academy, the Royal Meteorological Society of London, and the Societa Meteorologica Italiana.

In 1840, Loomis married Julia Elmore Upson of Tallmadge, Ohio who died in 1854. They had two sons, one of whom, Francis Loomis (1842–1918), earned two Ph.Ds in astronomy, the first from Yale University in 1866, and another from Göttingen University in 1869. When Elias Loomis died, he willed his $300,000 estate to the Yale Department of Astronomy, the interest (after lifetime provision for his sons) to be devoted to salaries for the observation and reduction of astronomical data, and defraying costs of their publication.

Dorrit Hoffleit

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Lord Kelvin

➜ **Thomson, William**

Lorentz, Hendrik Antoon

Born **Arnhem, the Netherlands, 18 July 1853**
Died **Haarlem, the Netherlands, 4 February 1928**

Dutch physicist Hendrik Lorentz matriculated at the University of Leiden, earning a Ph.D. from there in 1875. His dissertation theoretically explained the Zeeman Effect. Lorentz eventually joined the faculty of his *alma mater*.

Lorentz discovered, independently from **George FitzGerald**, the phenomenon of the Lorentz–FitzGerald contraction and created the Lorentz equations (or transformations) that so influenced **Albert Einstein**. In his career he investigated electromagnetic theory, as well as the theories of motion, gravity, and thermodynamics.

Lorentz received the 1902 Nobel Prize in Physics along with **Pieter Zeeman**. Their prize-winning work has great astrophysical application because it showed how spectral lines could be used to measure the magnetic fields of the Sun, stars, and interstellar gas.

Daniel Kolak

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Lorenzoni, Giuseppe

Born **Rolle di Cison di Valmarino, (Veneto, Italy), 10 July 1843**
Died **Padua, Italy, 7 July 1914**

Giuseppe Lorenzoni was a pioneering solar spectroscopist, independent discoverer of the presence of neutral helium in the Sun, and director of the Padua Observatory (1878–1914). Lorenzoni attended primary schools in Follina (Treviso), under the instruction of his father, and in Treviso itself. Between 1856 and 1860, he was a student at the I. R. Scuola Reale Superiore in Venice, under the protection of Italian educationalist Luigi Alessandro Parravicini. Lorenzoni matriculated at the University of Padua in 1860 and received his degree in engineering in 1864. But in the previous year, he had gained a position at the Padua Observatory as assistant to the elderly director, **Giovanni Santini**. In that same year (1863), Lorenzoni married Michelina Ferrari, but no children resulted from the marriage.

At the Observatory, Lorenzoni was entrusted with meteorological observations, and in a short time was able to replace obsolete instrumentation, to have a new meteorological station built to the north of the observatory tower, and to continue those observations, which today extend back almost 200 years. Lorenzoni carried out analyses of rainfall in Padua extending nearly 150 years, and wind directions for over 10 years.

In 1867, Lorenzoni began teaching theoretical geodesy and astronomy (the latter in place of Santini) while supporting various management duties at the observatory. He also began making astronomical observations, chiefly of meteors, which **Giovanni Schiaparelli** had recently demonstrated to be "cometary dust."

Lorenzoni first approached the new science of astrophysics on the occasion of a total solar eclipse, visible from Sicily in 1870. To partake in this astronomical event, a scientific commission was created by the Italian king. Santini was appointed president of the commission and charged with organizing the expedition and planning its scientific observations. Lorenzoni was assigned the task of observing the solar corona and prominences by means of a Hofmann direct-vision spectroscope, purchased expressly by the commission. This cooperative endeavor suggested to **Angelo Secchi** the formation of a *Società degli Spettroscopisti Italiani* to coordinate observations of the Sun. In 1872, the first issue of the *Memorie della Società degli Spettroscopisti Italiani*, the world's first astrophysical journal, was published. Lorenzoni became its lead author. One of the bright emission lines that he observed (λ 4471 Å) during the eclipse was that associated with neutral helium. Only later did Lorenzoni come to learn that the same spectral line had been previously noted by American astronomer **Charles Young**.

In the coming years, Lorenzoni took part in the program of spectroscopic observations coordinated by **Pietro Tacchini** in Palermo and Secchi in Rome. But the unfavorable climate of Padua, the difficulties of observing from the top of the observatory tower with a small 11-cm equatorial telescope, the lack of funds needed to update the obsolete astronomical equipment, and finally the task of helping Santini, all prevented Lorenzoni from devoting himself more fully to research in the "New Astronomy."

In 1873, Lorenzoni was appointed a member of the Italian Geodetic Commission (replacing Santini), and from then onward his main activities consisted of measurements of longitude and relative gravity and of coordinating the commission's work. The Italian government was more concerned with financing geodetic studies and the preparation of new geographic maps of Italian territory than in purchasing new expensive telescopes. Lorenzoni made important contributions to geodetic studies, *e. g.*, his determination of absolute gravity (1888) on the ground floor of the observatory tower, using a Repsold instrument, was well known. But he did not neglect astronomy.

During these years, Lorenzoni improved his knowledge of the mechanics and optics of astronomical and geodetic instruments. In 1874, he took charge of all the instruments in the observatory workshop in preparation for shipping them to India for the Italian mission (led by Tacchini) to observe the transit of Venus. In 1881, he was able to purchase a 187-mm Merz refractor, which the observatory later used in the determination of the solar parallax during the opposition of asteroid (433) Eros in 1900. Concurrently, Lorenzoni was appointed professor of astronomy at the University of Padua in 1872, and became full professor and director of the observatory in 1878, after Santini's death.

Lorenzoni is remembered as an outstanding teacher at the University of Padua. He had many clever pupils, including **Antonio Abetti**, who became director of the Observatory of Arcetri; Giuseppe Ciscato, director of the latitude station of Carloforte (Cagliari); Bortolo Viaro, who became director of the Observatory of Catania; mathematician Tullio Levi-Civita; **Emilio Bianchi**, director of the Observatory of Brera-Milan; Antonio Maria Antoniazzi, who succeeded Lorenzoni as director of the Observatory of Padua; and many others.

Finally, Lorenzoni published careful research on the history of the Padua Observatory, dating from 1767, and of his predecessors, especially Giuseppe Toaldo and Santini.

Luisa Pigatto

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Lovell, Alfred Charles Bernard

Born **Oldland Common near Bristol, Gloucestershire, England, 31 August 1913**

Bernard Lovell, together with Martin Ryle and Stanley Hey, were responsible for the early development of the discipline of radio astronomy in Britain.

Lovell was the only child of Gilbert Lovell and Emily Laura Adams. In 1931 he enrolled as a physics student at the University of Bristol and stayed on to do postgraduate research. Lovell obtained his Ph.D. degree, with a thesis concerning the electrical conduction characteristics of thin metal films, in 1936. That same year he was appointed a lecturer in physics at the University of Manchester.

At the University of Manchester Lovell worked with the eminent physicist **Patrick Blackett**. Blackett was convinced that the energy spectrum of cosmic-ray particles would reveal some hidden fact of cosmic significance, and Lovell was assigned the task of measuring particle energies using a cloud chamber. But when World War II broke out, he was told to report to a military installation on the English coast and found himself working on the fledgling techniques of radar detection. Lovell's wartime work included the development of early versions of the lock-and-follow radar fitted to various Royal Air Forcé fighter squadrons, and later, a ground-targeting radar system known as H_2S, which was fitted to Stirling and Halifax bombers.

Once the war was over, Lovell was released from his duties and returned to research at the University of Manchester. In the course of his wartime work he had witnessed sporadic, unexplained echoes on coastal defense radar systems and had wondered if these were due to the passage of cosmic rays through the atmosphere. Lovell acquired some ex-army radar equipment to investigate this idea and installed the system at a rural site called Jodrell Bank (some 20 miles south of Manchester) in order to escape the radio interference in the center of the city. He soon found that these radar echoes were not from cosmic rays but from meteor trails. Throughout the late 1940s Lovell and his coworkers investigated meteor trajectories and velocities using radar techniques and were able to show that many meteors originate in the dust tails of comets. Inspired by the emerging science of radio astronomy, they eventually turned their attention to detecting cosmic radio waves, and an early telescope at

Jodrell Bank was the first to discover radio waves coming from the Andromeda galaxy, M31.

Circa 1950, Lovell developed plans for an ambitious new telescope at Jodrell Bank. Construction of the 250-ft.-wide telescope, still the world's largest fully steerable radio telescope, began in 1952. The project suffered from rising costs and was almost cancelled on several occasions, Lovell himself narrowly avoiding imprisonment as a result. The telescope was eventually completed in the summer of 1957. That October, the Soviet Union launched the first artificial satellite, Sputnik I, into Earth orbit, and the telescope at Jodrell Bank was famously able to track the carrier rocket by radar. It continued to play an important part in the early days of space exploration, *e. g.*, receiving the transmission of the first photograph of the farside of the Moon from the Soviet Lunik 3 probe. The telescope, which was named the Lovell telescope in 1987, in honor of its founder, has been crucial in the discovery of quasars, the confirmation of the existence of pulsars, and the detection of maser emission from star-forming regions.

Lovell's legacy is immense. The telescopes he conceived and initiated continue to play a critical role in the study of diverse astronomical phenomena. Lovell was elected to the chair of radio astronomy at Manchester in 1951 and was director of the Nuffield Radio Astronomy Laboratories (now named Jodrell Bank Observatory) until his retirement in 1981. He was knighted in 1961.

Alastair G. Gunn

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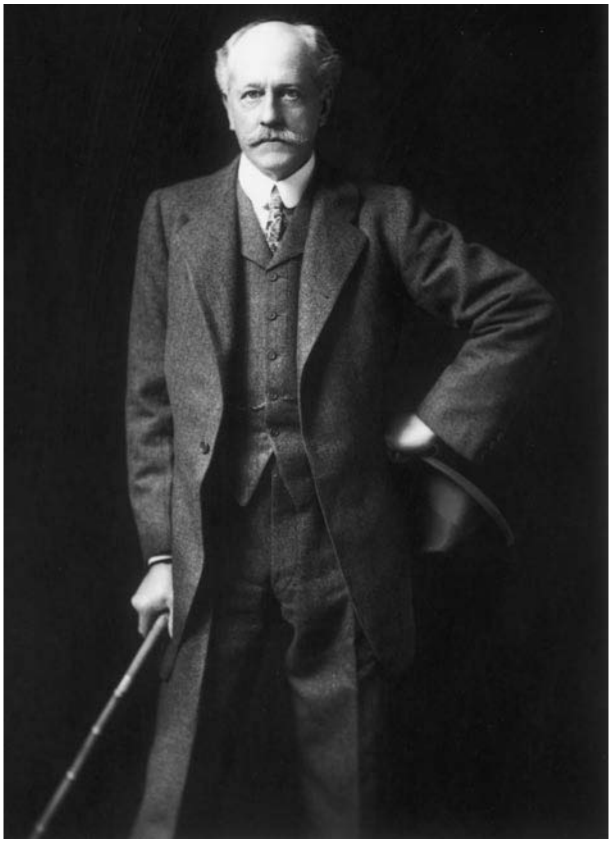
Lowell, Percival

Born **Boston, Massachusetts, USA, 13 March 1855**
Died **Flagstaff, Arizona, USA, 12 November 1916**

Percival Lowell's fame and notoriety arose from his claims about the existence of intelligent life on Mars, based on what he regarded as irrefutable evidence for network of canals on the surface of the planet visible from the Lowell Observatory. These sensational claims obscured much of his other work including the search for a ninth planet in the Solar System, which eventuated after his death in the discovery of Pluto, and his interest in cosmogony, which was explored in three books and numerous articles. Even less attention has been paid to his 10-year-long exploration of East Asian culture, which, together with his planetary research, was intended to provide further support for Herbert Spencer's monumental synthetic philosophy.



Son of Augustus and Katharine Bigelow (*née* Lawrence) Lowell, Percival Lowell was born into a wealthy and distinguished Boston family. On both sides, he descended from the original investors in the Lowell and Lawrence cotton mills. Among his siblings, younger brother A. Lawrence Lowell succeeded to the presidency of Harvard University in 1909, while sister Amy achieved renown as a cigar-smoking poet and one of the leaders of the imagist movement. Percival Lowell graduated from Harvard University in 1876 and launched a career as an investor in Boston; in 1883 he made his first trip to Japan. Over the next 10 years, he made four additional trips to Asia before turning to astronomy in 1894. On 10 June 1908 at the age of 53, Lowell married Constance Savage Keith, a union which produced no offspring.

Lowell's interest in Japan grew out of boredom with the routines of business life and impatience with the parochialism of his Boston family and friends. Through his travels, he hoped to create a more interesting life for himself, overcome his parochialism, and obtain a clearer sense of the racial hierarchy among peoples of the world. In the course of his travels, Lowell explored geographical sites and cultural phenomena then unknown in the west. Following a visit to Korea in 1883, he became the first westerner to write about that newly opened country based on firsthand observation. Lowell also visited and described the remote Noto Peninsula in Japan. His discovery, on Mount Ontake, of Shinto pilgrims who put each other into trances became the subject of *Occult Japan* (1894), an important contribution to the literature on subconscious states of mind. But Lowell's books on Japan will be best remembered for their insistence on the arrested mental development of the Japanese, which rendered them incapable of understanding western science.

Immediately following his return to Boston from Japan, Lowell made a sensational debut in astronomy by funding an expedition to Flagstaff, Arizona designed to take advantage of the 1894 Martian opposition to look for evidence of life on Mars. For this purpose, he hired as his assistants **William Pickering**, brother of **Edward Pickering**, the director of the Harvard College Observatory, and **Andrew Douglass**. Pickering and Douglass had recently returned from a stint at the Arequipa (Peru) station of the Harvard College Observatory. Following their recommendation, the Lowell Observatory was located in a similar high desert environment near the San Francisco Mountains, which could be expected to foster good seeing and clear skies.

Lowell's Martian observations in 1894 and during subsequent oppositions of the planet attracted widespread attention. Leading figures in the astronomical community disputed the existence of the canals on Mars as well as Lowell's contention that the Martian atmosphere could support intelligent life. Lowell, however, was undeterred by his critics. During the oppositions of 1905, 1907, and 1909, Lowell offered fresh evidence for the existence of the canals and in 1907 financed an expedition to Chile, under the leadership of his friend, the Amherst astronomer **David Todd**, to clinch the case for the existence of life on Mars. Nonetheless, by 1909, a consensus had developed among leading professional astronomers, including **Edward Barnard**, **George Hale**, and **William Campbell** based on their own observations, that there was no credible evidence for the existence of the canals or of intelligent life.

Meanwhile, Lowell launched two less sensational projects, which he may have hoped would improve his reputation in the astronomical community. In 1905, he began both a mathematical and an observational search for a ninth planet in the Solar System based on unexplained perturbations in the orbit of Uranus. These explorations continued unsuccessfully until Lowell's death in 1916. Fourteen years later, after the Lowell Observatory renewed the search for planet X, a new planet – different from Lowell's predicted planet in size and orbit – was discovered by **Clyde Tombaugh**, a young assistant at the observatory. Recognition of Lowell's role in this discovery was reflected in the presence of his initials in Pluto, the chosen name for the planet.

Lowell also forcefully entered the debate over the origins of the Solar System. Ever since his undergraduate years, he had endorsed the nebular hypothesis which identified the origin of the Solar System in a gaseous nebula. Not until 1902, when the nebular hypothesis was under attack, did Lowell take up this issue systematically in a series of lectures delivered at the Massachusetts Institute of Technology. Over the next 14 years, he published three books that endorsed a modified version of the nebular hypothesis as well as Herbert Spencer's notion that the continuing operation of evolution after the formation of the Solar System had produced an increasingly heterogeneous world of inorganic, organic, and social forms. As with his Martian findings, Lowell's Spencerian interpretation of history was attacked, this time by specialists in various fields.

The controversial nature of his work notwithstanding, Lowell contributed in important ways to the advancement of astronomy and of Asian studies. In the latter field, he called attention to the distinctive attributes of Japanese culture and to its artistic achievements. In the former, he inspired a succeeding generation of scientists to take up the search for extraterrestrial life. In this sense, Lowell might be regarded as a founding father of the Viking and Mariner missions. In addition, while sometimes diverting professional astronomers from other important work, the controversy over the canals of Mars called attention to research on the Solar System, which had been somewhat neglected. Lowell's legacy also included the observatory he founded, which was notable for its location and the staff he recruited. He helped to pioneer the exploration of good seeing in remote areas by making atmospheric conditions a key element in locating and maintaining the observatory in Flagstaff. Its successful operation was due to Lowell's recruitment of competent young astronomers who made important contributions to the profession. **Carl Lampland**'s photography of the nebulae was widely respected, as was **Earl Slipher**'s planetary photography. **Vesto Slipher**'s measurement of the high radial velocities of nebulae provided key initial evidence to support the concept of an expanding Universe. On Lowell's death and according to his wishes, V. M. Slipher assumed the directorship of the observatory.

While director of the observatory, Lowell served simultaneously as nonresident professor of astronomy at the Massachusetts Institute of Technology, where he gave occasional lectures. He was also fellow of the American Academy of Arts and Sciences, and a member of the Astronomical and Astrophysical Society of America. He was a Janssen Medallist of the Société Astronomique de France, 1904, and Medallist of the Sociedad Astronomica de Mexico, 1908. He received honorary degrees from both Amherst College, 1907 (LLD) and Clark University, 1909 (LLD).

David Strauss

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Lower, William

Born **Cornwall, England, 1569 or 1570**
Died **(Dyfed), Wales, 12 April 1615**

Sir William Lower was a gentleman and statesman who became a close collaborator of **Thomas Harriot**, through whom he obtained a telescope and made some of the first ever telescopic astronomical observations. Lower was the eldest son of and heir to Thomas Lower of Winnow. He attended Oxford University, entering Exeter College in 1586. He subsequently studied at the Middle Temple in London. Lower was elected to represent Bodmin, Cornwall, in Parliament in 1601; from 1604 to 1611, he represented Lostwithiel, Cornwall. He was knighted by King James I in 1603.

Around 1601 Lower married Penelope Perrot of Carmarthenshire, heir to the estate of her father, Sir Thomas Perrot. Lower moved to the Perrot estate at Trefenty near Saint Clears. When Lower died, he was survived by his wife and a daughter, Dorothy, but his wife was pregnant at the time of his death and later gave birth to a son, Thomas. Several other sons had predeceased him. His wife later remarried and moved to London.

Following the death of Perrot, Penelope's mother married the Earl of Northumberland in 1594, which brought Sir William and Northumberland into close contact. The latter was patron to Harriot, who lived at the earl's estate at Syon House, near London. Lower and Harriot began a productive friendship that lasted many years, corresponding regularly on scientific matters, with Lower acting as a confidant. It is from this correspondence that we know of Lower's scientific activities. These letters show a broad range of interests, including contemporary developments in astronomy, mathematics, and physics.

In 1607 Lower observed a bright comet first seen in September, now known to be comet 1P/Halley. He first noticed it in Ursa Major on 17 September while traveling across the Bristol Channel toward Wales. Lower made regular observations up to 6 October, using a cross-staff. These observations were sent to Harriot but were not published until 1784 (by **János von Zach**), being used by **Friedrich Bessel** to compute the orbit of the comet.

Harriot, who had a good knowledge of optics, learned of the development in 1608 of the telescope in the Netherlands. He experimented with his own telescopes before mid-1609 and presented Lower with an example manufactured by his assistant, Christopher Tooke, at Syon House. Lower used the instrument to make a series of observations of the night sky, aided by a friend, John Protheroe (or Prydderch) from the estate of Nantyrhebog (or Hawksbrook) not far from Trefenty. Lower enthusiastically requested Harriot to provide more telescopes for which he offered to pay. It appears that he observed from a building on some high ground at Trefenty, which was arguably among the very first observatories equipped with a telescope.

Lower's telescopic observations of the Moon have attracted the most attention. A letter to Harriot of 6 February 1610 has attained some notoriety. In this he wrote:

> According as you wished, I have observed the moone in all his changes. In the new manifestlie I discover the earthshine a little before the dichotomie; that spot which represents unto me the man in the moone (but without a head) is first to be seene. A little after, neare the brimme of the gibbous parts toward the upper corner appeare luminous parts like starres; much brighter than the rest; and the whole brimme along looks like unto the description of coasts in the Dutch books of voyages. In the full she appears like a tart that my cooke made me last weeke; here a vaine of bright stuffe, and there of darke, and so confusedlie all over. I must confess I can see none of this without my cylinder.

Lower received news of **Galileo Galilei**'s telescopic discoveries via Harriot shortly after the publication of *Sidereus Nuncius* and responded with excitement. He visited Syon House in December 1610, and he and Harriott observed the Galilean satellites of Jupiter. Lower was present when Harriot first observed sunspots at sunrise that month. However, on returning to Carmarthenshire, neither he nor Protheroe could see the Galilean satellites, indicating the lower quality of their telescope compared to those of Harriot. Lower himself saw sunspots from Syon House in December 1611.

Lower and Harriot failed to publish their results – unlike Galilei – even though they were often aware of their significance; indeed Lower's letters to Harriot included occasional pleas for Harriot to publish his scientific findings. Galilei's discoveries therefore made a major impact on scientific thought while Lower, perhaps understandably, has received only modest attention.

J. Bryn Jones

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Löwy, Kornel

➲ **Lanczos, Cornelius**

Löwy [Loewy], Maurice [Moritz]

Born **Marienbad (Mariánské Lázně, Czech Republic), 15 April 1833**
Died **Paris, France, 15 October 1907**

Paris Observatory director Maurice Löwy earned his reputation in celestial mechanics, particularly for his work on determining the orbital parameters of asteroids. He was born to a Jewish family, not, as is sometimes said, in Vienna but in Marienbad, at the time a city in the Austro–Hungarian Empire but now located in the Czech Republic not far from the German border. When Löwy was 8 years old, his family arrived in Vienna in order to avoid the endemic Jewish persecutions of the day.

In 1856, Löwy worked as an assistant at the Vienna Observatory, where his work on orbits of newly discovered minor planets drew considerable attention. Nevertheless, in the middle of the 19th century, the administration of the Austro–Hungarian Empire did not allow any Jewish-born person to obtain a university teaching position without converting to Catholicism. Because Löwy refused to renounce, he could not find any permanent position in Austria.

Fortunately for Löwy, **Karl Littrow**, director of the Vienna Observatory, enjoyed a very good scientific relationship with French astronomer **Urbain Le Verrier**, director of the Paris Observatory. During 1860, Littrow seems to have asked Le Verrier to welcome Löwy as a trainee assistant in Paris. After Le Verrier agreed, Löwy began his fruitful work at the Paris Observatory on 15 August 1860. Löwy served as deputy headmaster there from 1878 to 1896, and succeeded **Felix Tisserand** as director in 1896, a position he held until his death.

Löwy first carried out an investigation of the orbital parameters of comets and small planets, especially comet C/1858 L1 (Donati) and the minor planets (45) Eugénia and (99) Dike. He also participated in astrometric observations, including meridian passages. After a few years, Löwy earned the title "astronomer." When he obtained French citizenship on 4 July 1868, he changed his name to Maurice Loewy, which he retained the rest of his life.

From 1873 to 1880, Löwy specialized his work in astrometry. He accomplished thorough measurements of longitude differences. He was also involved in the improvement of the yearly *Connaissance des Temps*, published by the French Bureau des longitudes, as well as in the improvement of methods to determine astronomical refraction and aberration.

At the same time, Löwy also worked on enhancing astronomical instrumentation, especially telescopes. He developed the principle of the equatorial coudé telescope, six of which were constructed around the world. The first equatorial coudé telescope, equipped with a 27-cm lens, was installed at the Paris Observatory in 1882. The grand equatorial coudé, equipped with a 60-cm lens, was finally installed in 1890 at the Paris Observatory with the financial help of the generous patron Raphaël Bischoffsheim (1823–1906). Both instruments were built by the French opticians **Paul** and **Prosper Henry** in Paris.

Using the grand equatorial coudé, it was possible to obtain a very precise photographic map of the Moon for the entire visible disk and with a good level of homogeneity. Löwy's *Atlas photographique de la Lune*, with 10,000 photographic plates, was realized in collaboration with the French astronomer **Pierre Puiseux** between 1896 and 1910. This atlas served half a century for many selenographic studies and was the standard reference for lunar geography. The grand equatorial coudé remained in use after 1910 for astrophysical investigations, especially in spectroscopy, but the results were not excellent. After the dismantling of the telescope, the 60-cm lens was transferred to the Pic du Midi Observatory, where it is still in use.

As director of the Paris Observatory, Löwy reorganized its scientific programs and created a board of physical astronomy. In 1900, he proposed an international campaign for observing the recently discovered minor planet (433) Eros in order to determine the value of the solar parallax. Until then, the value had not been clearly ascertained, based mainly on rare Venus transits or on Mars perihelic oppositions. Fifty-eight observatories took part in the new project, which involved many photographs over several years. The Paris Observatory coordinated the observations and conducted the calculations. The final results arrived only after Löwy's death: a solar parallax of 8.806″ (currently accepted value = 8.794″).

During the French Council of Observatories held at the Ministry of Public Instruction for the designation of the new directors of the Marseilles and Algiers Observatories (while speaking in favor of one of the candidates), Löwy died suddenly from a heart attack. He had spent more than 50 years working in astronomy.

In honor of his work, Löwy received the prestigious Gold Medal of the Royal Astronomical Society of London in 1888. He was a member of the Bureau des longitudes (1872) and of the Académie des sciences, where he was elected a member of the astronomical section (7 April 1873), vice president in 1893, and president in 1894. He was also a member of the Comité Permanent de la Carte du Ciel, then its president. A 22 by 26 km embanked lunar crater, located at 33° west and 23° south in the east side of Mare Humorum, has been named in his honor.

Christian Nitschelm

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Loys de Chéseaux, Jean-Philippe

Born **Lausanne, Switzerland, 4 May 1718**
Died **Paris, France, 30 November 1751**

A simple question that arises from nature is, "Why is the sky dark at night?" The darkness of the nocturnal sky has intrigued observers for centuries, but it was necessary to wait until the 18th century to recognize that the reason for the sky's darkness was not at all obvious. It was a young Swiss astronomer, Jean-Philippe Loys de Chéseaux, who provided one of the first formulations of the problem in 1744, although **Johannes Kepler** had arrived at a similar conclusion *circa* 1610.

Loys de Chéseaux was the son of Paul Loys, the Seigneur of Chéseaux, and grandson of the mathematician and philosopher Jean-Pierre de Crousaz, a professor of mathematics and philosophy at the Academy of Lausanne and a corresponding member of the Académie des sciences in Paris. Crousaz was also the first person in Lausanne to teach in the French language.

Loys de Chéseaux possessed a gift for languages – Latin, Greek, and Hebrew constituted some of his favorites – and exhibited an early predilection for the sciences. At a young age, he displayed an exceptional talent and a growing intelligence that allowed him, at the age of 17, to publish in Paris three essays under the title, "Essais de physique" (1735). The success of these publications enabled certain critics to detect hints of his grandfather's abilities in the writings.

To acquaint himself with astronomy, Loys de Chéseaux installed an observatory on his father's lands at Chéseaux. It was seemingly well equipped, having "a pendulum clock, (plus) a quadrant made from brass and complete with sights capable of accurately (measuring) angles as small as 15 seconds [of arc]." The observations that he made between 1736 and 1747 allowed him to prepare two manuscripts, *Traite de la Comète* (1744) and "Nouvelles méthodes" (1747). However, the latter remained unpublished.

At that time, many German princes went to Lausanne to study at the academy. A literary society was created at the residence of the Count de Lippe, where meetings were held every Saturday and members presented their works. Loys de Chéseaux attended one of these meetings, on 22 December 1742, along with his father. The works that they presented were "La réformation du calendrier," "Un catalogue des nebuleuses," "Discours sur la figure de la Terre," and "L'influence de l'exemple." Loys de Chéseaux did not read his *Traiti de la Comète* until 28 March 1744. When published that same year in Lausanne, it consisted of four parts. The first constituted an introduction "to facilitate its reading by non-mathematicians."

In this treatise, Loys de Chéseaux considers all of the observations he made of comet C/1743 X1 seen from late 1743 into 1744. He discusses both the instruments and the methods he used, and calculates an ephemeris for the comet. Three sets of observations are presented in the study: those made of the comet in Paris by **César Cassini de Thury**; those recorded in Geneva by Jean-Louis Calandrini, the mathematician who jointly held the first chair in mathematics at the Academy of Geneva along with Gabriel Cramer, and those recorded by Loys de Chéseaux on his lands. He also describes a method for determining the position, the size, and the form of the comet's tail.

Finally, there is a chapter "on the intensity of light, its propagation in the ether [,] and on the distance of the fixed stars," from which Loys de Chéseaux concludes that "either the number of stars is finite or it has to be assumed that interstellar space is filled with a light-absorbing fluid." This proposition forms the basis for what might be called Loys de Chéseaux's paradox, and which can be formulated as follows: Imagine the space surrounding us to be the superposition of spherical shells. In each of these supposed shells, a star is sending out quantities of light that, from our vantage point, varies inversely with the square of the distance. If space itself were infinite, then the sum of all these contributions would produce a sky that was brilliantly illuminated in all directions. However, this conclusion is plainly contradicted by what we observe in the night sky. This is the paradox of the dark night sky that was recognized by Loys de Chéseaux.

Loys de Chéseaux's work was then forgotten for more that three quarters of a century until, in 1823, the German doctor and naturalist **Heinrich Olbers** raised the same questions as his predecessor. A number of historians have mistakenly attributed the paradox to Olbers himself, and such references have, consequently, been made to Olbers's paradox (but sometimes to the de Chéseaux–Olbers paradox).

In Loys de Chéseaux's time, the Universe was believed to be static; its expansion and subsequent cooling remained unknown before the 20th century. In addition, it possesses a finite age and "radius" (or visual horizon), beyond which we cannot hope to see; its most distant objects are the oldest. More refined calculations have shown that, in order for the night sky to present as much light as the Sun, either the density of stars in space or the length of a star's average lifetime would have to be around 100 billion times greater than at present.

Loys de Chéseaux later discovered comet C/1746 P1. He forwarded an essay, "Nouvelle méthode de calculer la position des orbites des comètes òu de resoudre le problème des trajectoires cosmetiques," to the Académie des sciences in Paris, which named him a corresponding member in 1747. More than a century later, **Camille Bigourdan**, an astronomer at the Paris Observatory, found two manuscripts written by Loys de Chéseaux. They were "Memoire ou la grandeur de la Figure de la Terre" and "Nouvelles méthodes." The latter is divided into two parts. In its first part, Loys de Chéseaux presents an improved version of his theory formerly described in *Traite de la Comète*. In the second part, he proposes a new theory in which "the sun is the center of the movement of the comets" that travel in "orbits of which the plane passes through the center of the centripetal forces."

Loys de Chéseaux, who in addition was a theologian, calculated the movements of the Sun and Moon relative to those described in the *Book of Daniel* and the occurrences of equinoxes and solstices in Jerusalem at the time of the Old Testament story. He authored a "Dissertation chronologique" (1748), in which he tried to establish the date of the eclipse that occurred after Christ's death and, in this way, determine the exact time of the crucifixion.

The works of Loys de Chéseaux attracted the attention of the scientific community in his day. Many academies and learned societies named him as a corresponding member, including the academies of Saint Petersburg, Göttingen, and Stockholm, as well as the Royal Society of London. He was offered the opportunity of directing the observatory at Saint Petersburg but declined the invitation, preferring to live modestly on his native lands. In 1751, after much urging by his friends, he traveled to Paris, where Loys de Chéseaux was presented to the Académie des sciences. Tragically, he soon fell ill and died.

Isaac Benguigui

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Lubieniecki, Stanislaw [Stanislas, Lubienitzky]

Born **Racców near Cracow, Poland, 23 August 1623**
Died **Hamburg, (Germany), 18 May 1675**

Stanislaw Lubieniecki is remembered for a three-volume work on comets that he published in the mid-17th century. Lubieniecki's father, Krzysztof Lubieniecki, was head of the Unitarian community in his town. During the Thirty Years War, Raców, and the local academy where Lubieniecki studied, were largely destroyed. Afterward, his father educated him and took him on frequent voyages to meetings with the Polish aristocracy.

After traveling to the Netherlands and France, Lubieniecki returned to Poland in 1650; he became an assistant preacher at Torun in 1652 and then a vicar in Czarców. At the close of the Thirty Years War (1660), the Unitarians were accused of having collaborated with the Swedish army. Lubieniecki, who was involved in peace negotiations with Sweden, fled to Copenhagen. In 1661, he traveled to Hamburg and settled there the following year.

When the Great Comet C/1664 W1 appeared in the sky above Hamburg, Lubieniecki corresponded about this phenomenon with Petrus van Bruxelles and **Ismaël Boulliau** in Paris and Henry Oldenburg (secretary of the Royal Society) in London. Lubieniecki collected his observations and those of others into the three-volume *Theatrum Cometicum (1666–1668)*. The first volume was filled with letters regarding the subject, the second contained an extensive catalog of materials on previous comets, and the third dealt with the astrological significance of comets. Lubieniecki showed a depiction of the star of Bethlehem as a comet and argued that the great fire of London had been a product of divine retribution (foretold by the comet of 1664).

In 1667, Lubieniecki suffered religious persecution in Hamburg and removed to Altona, a neighboring Danish town. In 1674, he returned to Hamburg, although his theological and political opponents were still watchful. Lubieniecki's important account of his native country's religious turmoil, *Historia reformationis Polonicae* (1685), was published posthumously. Reportedly poisoned by a servant, Lubieniecki instead may have died from ergotism, a toxic fungus that was then quite common.

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Lucretius (Carus), Titus

Born ***circa* 99 BCE**
Died ***circa* 55 BCE**

Roman poet Lucretius popularized **Epicurus**'s infinite Universe.

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Ludendorff, Friedrich Wilhelm Hans

Born **Thunow near Köslin, Poland, 26 May 1873**
Died **Potsdam, Germany, 26 June 1941**

Hans Ludendorff's many publications in *Astronomische Nachrichten* summarize his work in photometry, spectroscopy, double stars, variable stars, and statistical analyses of radial velocities.

Ludendorff earned his Ph.D. in 1897 from the University of Berlin. He served as an assistant at Hamburg Observatory before transferring to the Potsdam Observatory. There, Ludendorff served as *observator* (observer) from 1905 to 1915 and as *hauptobservator* (chief observer) until 1921, when he succeeded **Gustav Müller** as director, a position he held until 1939, when he retired. Ludendorff was, with Müller, the editor of the quarterly journal of the Astronomische Gesellschaft.

Ludendorf's early papers discussed observations of comets and minor planets, but he later devoted his attention to variable stars, especially those of long period, for which he established a classification scheme. Toward the end of his life, he became a scholar of Mayan astronomy.

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Lundmark, Knut Emil

Born **Älfsby, Sweden, 14 July 1889**
Died **Lund, Sweden, 23 April 1958**

Swedish astronomer Knut Lundmark is best remembered for having been the first to propose Crab Nebula as the remnant of the 1054 guest star (supernova) on the basis of its location, quite close to that given in translated Chinese records. He also almost discovered what is now called Hubble's law. Lundmark was the son of Johann August Lundmark (1848–1896) and Lovisa Eriksdotter (1852–1939) and married Birgit Lundmark (1886–1974) with whom he is buried in the churchyard in Älfsby.

Lundmark began studies at the University of Uppsala in 1908, receiving a first degree in 1912 and a doctorate in 1920 for a thesis, carried out under **Östen Bergstrand**, on methods of distance measurement in astronomy, including the apparent diameters and apparent brightnesses of nebulae, individual very bright stars, and nova explosions, and calibrating these on known events in the Milky Way. He derived a distance to M31, the Andromeda Galaxy, of 175,000 parsecs, about one-quarter of the best modern distance, at a time when the majority of astronomers doubted the very existence of galaxies outside our Milky Way. Lundmark worked as an assistant at Uppsala Observatory until his appointment as professor of astronomy at Lund University (where his predecessor had been **Carl Charlier**) and remained at Lund for the remainder of his career, mentoring **Bengt Stromgren**, among others.

An appendix to Lundmark's thesis suggested (as **Heber Curtis** advocated at the same time) that there might be two classes of novae of very different brightness. Lundmark's class of "giant" or "upper class" novae consisted of what we now call supernovae, which were recognized by **Walter Baade** and **Fritz Zwicky** in 1933/1934. Baade and Zwicky generally receive credit for the idea.

Later Lundmark called attention to the discrepancy between distances to Andromeda determined from Cepheids and from three other methods based on novae, giant stars, and globular clusters. In his review published in 1946 the first three gave an average 540 kpc, while Cepheids indicated a shorter distance, 400 kpc (even with the new zero-point of the period–luminosity relation, derived by **Henri Mineur** in 1944). The higher value heralded the approaching reformation in the old distance scale based on Cepheids. In this review Lundmark concluded that supernovae, which he had identified as a class 25 years earlier, seem to furnish an excellent distance indicator, with a small scatter in their maximum luminosity. The work with low and high redshift Type Ia supernovae in recent years has confirmed this.

Lundmark played an interesting role in the debate on the detectable rotation in spiral nebulae. During his visit to the Mount Wilson Observatory in 1921–1923, Lundmark measured proper motions on **Adriaan van Maanen**'s plates of M33, which according to Van Maanen showed rotation (as did some other nebulae measured by him, suggesting very short distances). Lundmark did not find any systematic motions.

In 1924, Lundmark attempted to determine the motion of the Sun relative to the spiral nebulae, whose radial velocities had been measured by **Vesto Slipher**. He allowed for the possibility of overall expansion or contraction of the system of nebulae, which might depend on distance, through what was called a K term. The correlation Lundmark suggested began with velocities increasing with distance near us, but turned over with a negative quadratic term, which would have prevented any velocities larger than about 3,000 km/s ever being seen. Thus it was left for **Edwin Hubble** in 1929 to find the linear relation that we now call Hubble's law and interpret it as evidence for overall expansion of the Universe.

The work of Hubble and Lundmark on classifying the main types of galaxies also overlapped in time, with Hubble again getting most of the credit, perhaps less fairly in this case. Both recognized spiral and elliptical types and a less orderly class of irregulars, including the Magellanic Clouds.

Following Charlier's ideas, Lundmark had expected a hierarchical arrangement of structure in the Universe, with clusters of galaxies, clusters of clusters, and so forth. His attempt to compile a catalog of galaxies sufficiently extensive to reveal such structure failed to attract sufficient labor and funding from the community. (It is now known that instead of a stiff hierarchy, there is a fractal-like distribution with a possible cross–over to homogeneity around 100 MPC). Lundmark also made significant contributions to stellar astronomy (reviewed in the *Handbuch der Astrophysik* in 1932/1933) and to teaching and public education, *via* lectures, popular articles, and books. He apparently never felt entirely at home within a Universe of finite age and, perhaps, finite size, so different from that envisioned by his childhood hero **Camille Flammarion**.

Pekka Teerikorpi

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Luther, Karl Theodor Robert

Born **Schweidnitz (Swidnica, Poland), 16 April 1822**
Died **Düsseldorf, Germany, 15 February 1900**

Karl Theodor Robert Luther was a zealous discoverer of minor planets during a time when photography was not available to make the task easier. He was born to August Luther and his wife, Wilhelmine von Ende. After being educated at home and at the local high school, Robert went to Breslau (1841–1843) and Berlin (1843–1848) to study astronomy. Luther enjoyed a long and productive career. He died after a short illness, survived by his son, Wilhelm, and his wife, Caroline (*née* Märker), whom he had married in 1859.

In 1843 at Berlin as the pupil of **Johann Encke**, Luther helped with calculations for an astronomical almanac. In 1850, he was promoted to second observer and worked at the 9-in. refractor. At the end of 1851, astronomer **Franz Brünnow** invited Luther to come to the Charlottenruhe Observatory in Bilk near Düsseldorf to succeed him there as director. This small observatory, founded by **Johann Benzenberg** in 1844, was equipped with a 4.6-in. aperture, 6-ft. focal length Merz refractor; it was replaced in 1877 by another Merz, this one being a 7.3-in. aperture, 7-ft. focal length refractor on a Bamberg mount.

Luther concentrated on positional observations, and found 24 minor planets between (17) Thetis in 1852 and (288) Glauke in 1890. He regularly observed five minor planets – (6) Hebe, (11) Parthenope, (56) Melete, (61) Danaë, and (288) Glauke – yielding orbital parameters of high accuracy. Luther also made observations for the Berlin celestial chart, which led to positions for 4,302 stars. In his latter years, his sense of hearing faded, making impossible the "eye-and-ear" method of positional astronomy. In leaving the observations to his son Wilhelm, Robert Luther instead concentrated on the necessary calculations.

Luther was honored several times for his observations. On 9 June 1854, he was elected associate of the Royal Astronomical Society in London, and in 1855, he received a honorary Ph.D. from the University of Bonn. Between 1852 and 1861, Luther was presented with the Prix Lalande seven times by the Academy of Sciences in Paris. In 1863, he joined the Astronomische Gesellschaft as one of its first members, and in 1868 the Société Impériale des Sciences naturelles de Cherbourg. On 4 March 1897, he was given the title of honorary professor by Kaiser Wilhelm I. Luther is also honored by the minor planet (1303) Luthera and a lunar crater name.

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Luyten, Willem Jacob

Born **Semarang, (Indonesia), 7 March 1899**
Died **Minneapolis, Minnesota, USA, 21 November 1994**

Dutch–American observational astronomer Willem J. Luyten is best remembered for the discovery and cataloging of a very large number of stars that move rapidly across the sky, either because they are very close to us, because they are old and genuinely fast moving, or both. Luyten was raised on the island of Java by parents from the province of North Holland, who had settled in what was then the Dutch East Indies, where his father taught French in the local high school. He was fluent in French, Dutch, German, and English by the time he graduated from high school in the Netherlands, where the family had relocated in 1912, and added other languages later. His interest in astronomy was aroused by the sight of Halley's comet (IP/Halley) in 1910.

Luyten began making and publishing astronomical observations (mostly of variable stars) in 1912, and, with a last paper in the year of his death, his record of publication through 72 years is close to a world record. Luyten received a BA from the University of Amsterdam in 1918 and a Ph.D. in 1921 from the University of Leiden, where he worked with **Ejnar Hertzsprung** on stellar motions. He held positions at Leiden (1920/1921), Lick Observatory (1921–1923), Harvard College Observatory under **Harlow Shapley** (1923–1927), and the University of Minnesota (assistant to associate to full professor to emeritus).

From the beginning Luyten made extensive use of a method (invented by Hertzsprung) by which the apparent brightness of a star and the rate at which it moves across the sky (its proper motion) could be combined to yield an estimate of distance. He was therefore able to provide the first realistic census of the numbers and types of stars in the solar neighborhood, extending eventually to stars only 0.01% as (intrinsically) bright as the Sun.

During the last 2 years of his Harvard appointment, Luyten worked at Bloemfontein, South Africa, where he met and married Willemina Miedema. Their three children all entered into professional employment. He used the Bruce telescope (which Harvard had moved to South Africa from Arequipa, Peru in 1910) to obtain about 300 plates of the southern sky, beginning a second complete southern survey that could be compared with the first 1896–1910 set of images to look for stars whose location had changed. Luyten himself examined all plate pairs with a blink comparator (which flashes two images back and forth quickly, so that the observer can look for changes in brightness and position). Luyten and his colleagues (including the author) eventually found 94,263 stars with significant motions, with the final catalog appearing in 1963. The so called Luyten "Proper Motion Catalogues" remain a fruitful source of interesting, faint, and nearby stars down to the present.

The "Bruce Proper Motion Survey" also yielded a rich harvest of the burnt-out stars called white dwarfs (sometimes known as degenerate dwarfs because their pressure comes from electrons crowded tightly together). Luyten collaborated with E. F. Carpenter of the University of Arizona, E. Gaviola of Cordoba Observatory, and **Guillermo Haro** of Tonantzintla Observatory in Mexico to obtain colors, and later spectra, of the faint stars in the survey. He was responsible for the largest collection of precise data for white dwarfs until Olin J. Eggen and **Jesse Greenstein** took up the problem in 1963 with the Palomar 200-in. telescope. Luyten recognized the categories whose surfaces were covered with thin layers of hydrogen (commonest), helium, or, in one case (Van Maanen's star), calcium and iron.

In order to extend the search for nearby stars still fainter and into the North Celestial Hemisphere, Luyten tackled the problem of making precision measurements of the thousands of 6° × 6° plates being exposed in the National Geographic/Palomar Observatory Sky Survey (named for its principal financial supporter and for the

Palomar Schmidt telescope where all the plates were exposed). He quickly realized that a traditional blink comparator would require hundreds of astronomer-years to examine all the plate pairs (perhaps even more so for him, since he had lost the sight of one eye in a tennis accident in 1925). Luyten approached the Control Data Corporation [CDC] with plans to build a device that would scan the plates rapidly and record the darkness of the exposed emulsion at each point (called a microdensitometer). The CDC machine, designed primarily by James Newcomb and Anton LaBonte, became the fastest of a new, 1960s generation of automatic machines for rapid plate measurements and comparisons. In a few years, the Minnesota group had found proper motions for about 300,000 stars, doubling the data base. The catalogs that emerged from this effort are among the most widely used in the field.

Luyten's technical publications numbered more than 500, in addition to popular articles for the *New York Times*, the *Minneapolis Star and Tribune*, and other papers. His honors included election to the National Academy of Sciences, the Bruce Medal of the Astronomical Society of the Pacific, and honorary degrees from Case Western Reserve and the University of Saint Andrews. He participated in eclipse expeditions to Ensenada, Mexico in 1923 and Lapland in 1927, and held Guggenheim fellowships in 1928–1930 and 1937/1938.

Luyten's relationships with the rest of the astronomical community were colored by impatience and a sharp tongue and pen when faced with work that he regarded as of less than the highest standard. Correctly measuring the apparent brightness of very faint stars is notoriously difficult, and he coined the name "The Weistrop watergate" for counts of the number of faint, cool hydrogen-burning stars nearby that he believed contained far too many such stars. For better or for worse, Luyten was right. Such stars are commoner than brighter ones like the Sun, but not so common that their collective mass dominates local galactic structure.

Arthur Upgren

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Lyot, Bernard

Born **Paris, France, 27 February 1897**
Died **Cairo, Egypt, 2 April 1952**

French planetary and solar astronomer Bernard Lyot built the first successful coronagraph and used it to record the first spectra and images of the solar corona taken outside total eclipses. Lyot, the son of a Parisian surgeon, built a small observatory at the age of 16 and joined the amateur Société Astronomique de France 2 years later, but studied engineering at the École Supérieure d'Électricité at the urging of his family. Graduating in 1917, in the midst of World War I, he soon found work at the École Polytechnique (Paris), working with physicist Alfred Pérot on aerial and maritime navigational aids for the French army. At the end of the war, Lyot became a teaching assistant in Pérot's laboratory and pursued a higher degree, demonstrating such dexterity and insight into optical instruments that Pérot recommended his appointment to the staff of the Meudon Observatory in 1920. He became assistant astronomer in 1925, astronomer in 1930, and chief astronomer in 1943.

Because reflected light is polarized, Lyot thought the reflected sunlight by which we see the Moon and planets should be too, and that existing polarimeters were simply not sensitive enough to see the effect. He built a photoelectric polarimeter with a sensitivity of a part in 1,000 and used it to show, from the amount of polarization as a function of the angle at which the light was reflected, that the Moon, Mercury, and Mars all have rather similar rocky surfaces, but that Mars has dust storms and the Moon probably a layer of volcanic ash. Lyot also thought he had detected water vapor features in the light reflected from Venus (but the actual amount is too small for him to have seen).

Lyot came to the idea of the coronagraph through wanting to observe Mercury as close in the sky to the Sun as possible, to see how the reflected light changed. Atmospheric dust at Meudon prevented this, so he went to the Pic du Midi Observatory high in the Pyrenees. This was better, but Lyot decided that a good deal of the scattered sunlight that kept him from seeing Mercury up close was actually being scattered in the observing equipment (contrary to the general wisdom of the time). He modified his telescope by covering the rim of his lens and placing a small circular disk where it would block direct sunlight, and was able to complete the planetary project. By chance, Lyot also saw a large prominence on the solar limb and resolved to attempt to study the corona without waiting for an eclipse the next year. The basic coronagraph design was similar: a lens with its edges blocked by a diaphragm and an occulting disk to block direct sunlight. He later added a second diaphragm to stop light diffracted around the edges of the first one. In 1930 and 1931, Lyot showed that the light getting through had the characteristic polarization seen during eclipses and saw the distinct coronal emission line at 5303 Å (whose cause was not then known). He took the first photographs of the inner corona outside an eclipse.

When solar activity began to resume in 1935, Lyot returned with an improved coronagraph, measuring very accurate wavelengths for the emission features (which eventually led to their identification with highly ionized atoms of common elements by **Walter Grotrian** and **Bengt Edlén**). Lyot also noted that the emission lines were very broad, suggesting that the corona must be exceedingly hot, as proved to be the case. He also began producing time-lapse films of prominence eruptions in a style pioneered by **Robert McMath**. These attracted a great deal of attention at the 1938 general assembly of the International Astronomical Union.

Lyot also developed a quartz-polaroid monochromatic filter, which would pass only the light of one emission line, for instance, Balmer α. The idea was originally his, though the first device was built and operated by **Yngve Öhman**. Lyot's passed an even narrower wavelength range, about 3 Å (versus 50 Å for Öhman's), and led to superlative movies of prominences and photographs of the corona.

Despite his having invented the device that made expeditions to observe solar eclipses unnecessary, Lyot was himself an enthusiastic participant in these, and it was a heart attack on the journey home from the exhausting mission to the Khartoum eclipse that led to his death. Lyot's work was recognized by election to the Académie des sciences, gold medals from the Royal Astronomical Society and from the Astronomical Society of the Pacific, and by the establishment of a commission of the International Astronomical Union which focuses on the kind of work he pioneered (chromospheric phenomena, later merged into solar activity).

Richard Baum

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Lyttleton, Raymond Arthur

Born **Oldbury, Worcestershire, England, 7 May 1911**
Died **Cambridge, England, 15 May 1995**

British theoretical astronomer Raymond Lyttleton worked primarily on dynamical problems, having put forward and explored the mathematics of a variety of ideas concerning the structure of comets, the origin of the Solar System, stability of rotating objects, accretion and evolution in binary systems, and the interior structure of the Earth.

Ray Lyttleton was the third child and only son of Irish parents, Agnes (*née* Kelly) and William John Lyttleton. He was educated in the schools of Birmingham and at Clare College, Cambridge, receiving a first class degree in the mathematical *tripos* in 1933. He was awarded a Ph.D. in 1937 for work done partly in Cambridge with **William Smart** on the three-body problem and partly in Princeton with **Henry N. Russell** on the formation of the Solar System (while he held a Proctor Visiting Fellowship). Lyttleton was a fellow of Saint John's College from 1937 onward and was appointed to a personal professorship in 1969. His war work applied mathematical ideas to supplies, the accuracy of antiaircraft shells, and minefield clearance.

Lyttleton's 1939 marriage to Meave Margaret Hobden remained childless. His recreations included cricket, piano playing, accurate writing of both fiction and nonfiction, golf, and, according to *Who's Who*, "wondering about it all." He received top-of-the-line medals from the Royal Society (London) and the Royal Astronomical Society, and served on enough committees and editorial boards to have concluded: that the optimum number of people on a committee is 0.7 and (2) that the average number of readers per technical paper also is 0.7, including the referee, but excluding the author.

Lyttleton's contributions were largely based on dynamical considerations, typical of applied mathematicians educated at Cambridge University. His thesis consists of two papers published in the *Monthly Notices of the Royal Astronomical Society*, which he wrote while visiting Princeton University under the influence of Russell. Theories of the origin of the Solar System widely accepted in the pre-World War II period were those of **James Jeans** and **Harold Jeffreys**, building on a late nineteeth century idea of **Thomas Chamberlin** and **Forest Moulton**, who postulated that a star either passed very close to or even collided with the Sun to pull out material that would later cool and form planets. Russell pointed out that most of the angular momentum of the Solar System is in the orbital motion of the planets, and that the theories of Jeans and Jeffreys could not give sufficient angular momentum to the material torn out of the Sun. Lyttleton showed that if the Sun were a member of a binary, and an intruding star either collided or passed very close to the companion, the angular momentum problem could be solved. The idea was later modified by **Fred Hoyle**, who postulated that the companion became a supernova and the remnants of the explosion were captured by the Sun to form the planets. Lyttleton also argued that Pluto was originally a satellite of Neptune, which escaped during a close approach Triton, the present satellite of Neptune.

The phenomenon of accretion takes place when a star enters a gas cloud. A significant amount of the gas cloud is accreted to the star, because the gas cloud is attracted to the star by its gravity. The material that falls upon the star generates heat. Lyttleton discovered this phenomenon with Hoyle, and attempted to explain the variation of the terrestrial climate by the Sun's encounter with interstellar clouds. Accretion is a mechanism whereby a large amount of radiation is generated, such as in x-ray sources or active galactic nuclei.

With Hoyle and Herman Bondi, Lyttleton also investigated the structure of red giants.

Another Lyttleton inquiry involved the stability of rotating liquid masses. The Earth is flattened toward the Equator owing to rotation. If the rotation were much faster, the flattening would be greater. Material that constitutes planets may be regarded as fluid when considered on a large scale. Mathematicians such as **Jules-Henri Poincaré** and **George Darwin** discussed the shapes that rotating liquid masses would assume. As the rotation gets faster, ellipsoids (with three different axes), and not spheroids (a form with axial symmetry), become possible figures of equilibrium. At a certain stage, these figures are no longer stable and begin to separate into two pieces. Some scientists assumed that binary stars might have formed this way. Darwin assumed that the Moon separated from the Earth owing to this instability, and the tidal friction subsequently brought the Moon to its present orbit. Lyttleton showed that separating two bodies could not form a binary: The two bodies formed by the instability would, in the absence of other gravitating bodies, recede to infinity from each other. He also showed on dynamical grounds the possibility that the two separating bodies would be the Earth and Mars, the Moon being a droplet between the two main bodies. It is interesting to note that at present, instead of the rotational instability, actual collision is suggested to account for the origin of the Moon.

It may seem curious, but until the middle of the 20th century, there was no consensus as to what comets were really made of. Accepting the model of a comet advocated by Russell, namely, that a comet is an aggregate of tiny particles, Lyttleton suggested that they are formed by accretion of interstellar dust grains. This theory has turned out to be untenable, and **Fred Whipple**'s theory of an icy nucleus model has come to be accepted. However, together with J. Hammersley, Lyttleton showed how quickly (astronomically speaking) comets are expelled from the Solar System by the perturbations of the major planets. Their theory is more rigorous than the work of Van Woerkom, on which **Jan Oort** developed the well-known idea of a cometary cloud surrounding the Sun. Lyttleton also pointed out that the distribution of perihelia of comets can be used to test a theory of their origin, or mechanism of supply, a method currently adopted in such investigations.

One of the other problems Lyttleton investigated with Bondi is a possible consequence of a hypothetical small difference between the charges of the proton and the electron. If there were indeed a small difference, that would contribute to the expansion of the Universe. Later, their assumption was tested to be negative, but it contributed to the reinvestigation of the basic assumption of physics.

A geophysical problem considered by Lyttleton is the possible shrinkage of the Earth needed to explain the formation of folded mountains. Before the plate tectonics theory came to be widely accepted, the well-known geophysicist **Harold Jeffreys** had calculated how much shortening of the Earth's circumference was needed to explain the formation of folded mountains. Lyttleton showed that if the core of the Earth were a high-pressure phase of the mantle material, a gradually growing core could provide the shrinkage. This is not tenable any longer; plate tectonics can provide viable explanation for the formation of folded mountains.

Again together with Bondi, Lyttleton investigated a fluid motion that could be induced in the Earth's core owing to a slowing down of the rotation by tidal friction.

Some of the ideas Lyttleton developed are now generally regarded as untenable. These include a tidal origin for the Solar System, a phase change rather than composition discontinuity between the mantle and core of the Earth, a rubble-pile picture of cometary nuclei, and a mass for Mercury small enough for it to be made of the same chemical mix as Venus, Earth, and Mars.

Shin Yabushita

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M

Maclaurin, Colin

Born **Kilmodan, Argyllshire, Scotland, February 1698**
Died **Edinburgh, Scotland, 14 June 1746**

Colin Maclaurin was, perhaps, the last of the great British mathematicians of the period following **Isaac Newton**. His geometrical methods influenced French work in celestial mechanics. An equilibrium shape of a rotating fluid body called a Maclaurin was thought for many years to be relevant to the formation of binary stars from single, rotating gas clouds.

Maclaurin's father, a parish Minister, died 6 weeks after Colin's birth, and his mother died when he was nine. His uncle, Daniel Maclaurin, Minister in Kilfinnan on Loch Fyne, took responsibility for him. In 1709, Maclaurin entered the University of Glasgow and, although a career in the church was originally intended, he was introduced to Euclid's *Elements* and turned his attention to mathematics and physics. After 4 years, he graduated MA with a thesis, "On the Power of Gravity."

In 1717, Maclaurin was appointed professor of mathematics at Marischal College, Aberdeen, aged only 19 (the youngest professor recorded at any university). Shortly afterwards, he became a good friend and disciple of Newton and, at this time, was elected to a fellowship of the Royal Society of London. Maclaurin travelled widely in Europe between 1722 and 1725. In 1724, he was awarded a prize from the Academy of Sciences in Paris for his work, "On the Percussion of Bodies."

Early in 1726, Maclaurin was appointed to the chair of mathematics at the University of Edinburgh, which he held for the remaining 20 years of his life. During this period, he was a major force in the world of mathematics. His contributions were not only to analysis and geometry but also to physics and astronomy.

During his time in Edinburgh, Maclaurin's efforts were important in the formation of scientific societies. A member of the Society for the Improvement of Medical Knowledge from 1731, he helped broaden its purview. The result was the new, more inclusive organization, the Philosophical Society of Edinburgh, founded in 1737. It was the latter society that, in 1783, was the catalyst for the foundation of the Royal Society of Edinburgh, which is still Scotland's premier learned society.

In 1733, Maclaurin married Anne Stewart, and this union produced 7 children.

An assessment of Maclaurin's place amongst the great mathematicians is obscured by, among other things, the difficulties in assigning priorities to certain mathematical discoveries. Nowadays, his name is known to all mathematicians because of Maclaurin's series. This result appeared in his book, *Treatise of Fluxions*, published in 1742, but the author acknowledged that it was a special case of an earlier result due to Brook Taylor in the latter's book, *Methodus Incrementorum* (1715). In any case, this result was, at least in some form, known to earlier workers, including **Jacob Bernoulli** and the Scottish mathematicians, **James Gregory** and James Stirling. On the other hand, Cramer's rule for systems of linear equations, Cauchy's integral test for convergence, and Bezout's theorem on the intersection of curves were developed by Maclaurin several years before those mathematicians whose names are now associated with them.

In the *Treatise of Fluxions*, Maclaurin gave a systematic account of Newton's theory of fluxions, mainly in response to an attack on these ideas by the Irish philosopher George Berkeley, in the latter's *Analyst* of 1734. Maclaurin's book also contained an account of his work on the gravitational stability of ellipsoids. This was accomplished by employing classical mechanics rather than fluxions. **Alexis Clairaut**, after reading Maclaurin's text, reverted to geometrical methods to attack the figure-of-the-earth problem.

Maclaurin also dealt with the tides (based on material that had previously been awarded a prize by the Paris Academy in 1740). In addition to the above, there were two other posthumous books, *Treatise of Algebra* and *An Account of Sir Isaac Newton's Philosophy*.

Maclaurin was also involved in some more practical branches of mathematics and in the organization of the defenses of Edinburgh against the Jacobite forces in 1745. When Edinburgh fell, Maclaurin fled to York. Although he soon returned, these exertions, together with a fall from a horse, seriously weakened his health, and he died shortly afterward.

Graham Hall

Alternate name

Cailean MacLabhruinn

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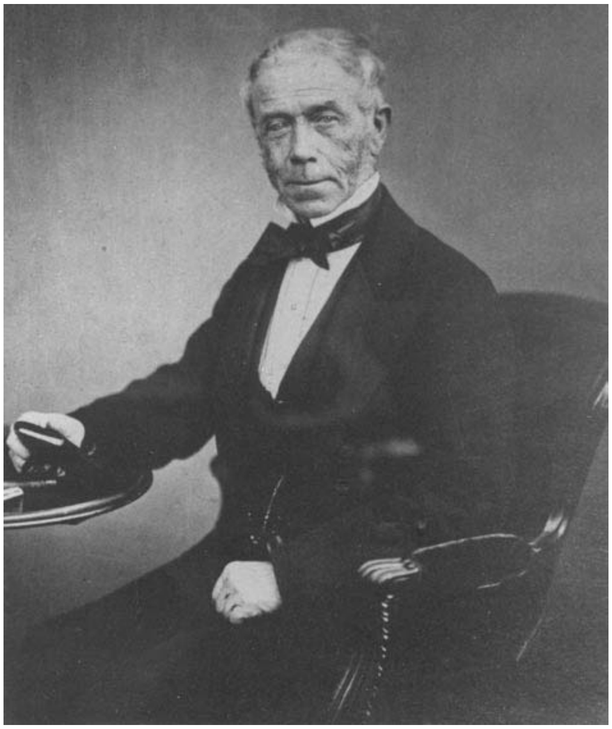

Maclear, Thomas

Born **Newtownstewart, Co. Tyrone, (Northern Ireland), 17 March 1794**
Died **Mobray near Cape Town, (South Africa), 14 July 1879**

Thomas Maclear, the third director of the Royal Observatory at the Cape of Good Hope, established it as a leading astronomical observatory during his 36-year tenure. Thomas, eldest son of the Reverend James Thomas Maclear and Mary Magrath of Newtownstewart, was sent at age 15 to England to be cared for by his mother's brothers. Thomas was apprenticed to one of them, Dr T. Magrath, an eminent surgeon at Biggleswade, near Bedford, 50 miles north of London.

In 1814, Maclear went to London to study medicine at Guy's and Saint Thomas's Hospitals, and was admitted a member of the Royal College of Surgeons in 1815. He accepted the post of house surgeon at the Bedford Infirmary and, in 1823, joined his uncle's medical practice. In 1825, Maclear married Mary Pearse. He became acquainted with captain **William Smyth**, who established an observatory nearby. Maclear frequently visited Smyth's observatory, where he met Francis Beaufort and **John Herschel**, who became his lifelong friends.

In 1828, Maclear joined the Astronomical Society of London, setting up his own observatory at Biggleswade using a small transit instrument and a Dollond refractor on loan from the society. Maclear became expert in predicting lunar occultations, and calculated the occultations of Aldebaran (1829–1831) for ten European observatories. He corresponded about occultations with **Thomas Henderson**, then director of the Royal Observatory at the Cape of Good Hope. Maclear was elected a fellow of the Royal Society in December 1831.

After Henderson's resignation from the Royal Observatory at the Cape of Good Hope, the Admiralty offered the position to Maclear. His uncle disapproved; Maclear's annual salary as doctor brought in about £800, whereas the Cape post offered only £600, and Henderson had warned him of many difficulties. Nevertheless, Maclear decided to go, perhaps comforted by Herschel's plan to travel to the Cape to carry out a survey of the southern skies.

Maclear and his family, including his wife, five daughters, a governess, a nursemaid, and a manservant, arrived at the Cape on 7 January 1834 after a grueling 3-month voyage. His youngest daughter was suddenly taken ill and died within 2 days. The Herschels arrived at the Cape soon afterwards; Maclear and Herschel kept in close contact by letter.

When Maclear arrived at the Cape, he immediately inspected the Troughton mural circle, which had given trouble to his predecessors, **Fearon Fallows** and Henderson. Maclear confirmed their opinions that only by averaging the readings on all six microscopes could reliable results be achieved with the mural circle, a cumbersome process that delayed observational progress. His progress was further delayed when his one assistant, lt. William Meadows, proved unsatisfactory and left in December 1834. Meadows was eventually replaced by **Charles Piazzi Smyth**, the second son of captain Smyth. Maclear and Herschel observed the reappearance of Halley's comet (IP/Halley) in 1836, and made accurate observations of its path. After Herschel departed for England in March 1838, he reported favorably on Maclear's work, and recommended sending him more equipment and assistants.

One of Maclear's original instructions was to remeasure the meridian arc that **Nicolas de La Caille** had measured during

1751–1753. The arduous survey required most of the observatory's resources from 1837 to 1847. It showed that La Caille's measurements had been accurate but had not made allowance for the gravitational attractions of mountains on the plumb-bob.

The establishment of a magnetic observatory in 1841 was part of a global network of magnetic and meteorological observatories promoted by general **Edward Sabine** and supported by Herschel and others. Buildings and instruments were set up and run for 3 years by a detachment of the Royal Artillery, but when the magnetic observatory was transferred to the Admiralty in 1846, Maclear was instructed to add these observations to his duties. The magnetic work declined after 1857 and ceased on Maclear's retirement in 1869.

In 1833, Henderson had established a time service for vessels moored in Table Bay. Each night, a gun was fired to synchronize marine chronometers. Captain Robert Wauchope improved it with a time ball, which slid down a pole at an advertised time. His idea was adopted immediately by the Royal Observatory, Greenwich, in 1833 and by the Cape Observatory in 1836. A second time ball was erected at Simon's Town in 1857; they were connected to the observatory by electric telegraph in 1861. By August 1865, Maclear proudly declared that each day at one o'clock, the observatory ball, the Simon's Town ball, the Cape Town time gun, and the Port Elizabeth ball were discharged simultaneously.

In 1845, when Piazzi Smyth was appointed to succeed Henderson at Edinburgh, Maclear appointed William Mann as his first assistant. Mann helped erect and operate three new refractors: A 3-in. Dollond, a 3-in. Jones, and a 7-in. Mertz. A transit circle by Troughton and Simms was erected in the room formerly occupied by the "Mural Circle." Observations started in January 1855.

In 1859, Maclear spent a few months visiting England, Ireland, Paris, and Brussels. In June 1860, he was rewarded with a knighthood. The death of his wife in July 1861 caused him much grief, but his large family – six children were born in Cape Town – provided comfort to him. For his work on the extension of La caille's arc measurements, Maclear received the Lalande Prize of the French Academy of Sciences in 1867. In 1869, he was awarded the Gold Medal of the Royal Society. Other awards included membership of the Academy of Sciences of Palermo (1835), corresponding member of the Imperial Geological Institute and Geographical Society of Vienna (1858), and correspondent of the Institute of France (1863).

Maclear was greatly interested in exploration; with John Herschel he served on the Committee of the Association for Exploring Central Africa. In 1850, Maclear met David Livingstone and taught him how to use a sextant. They remained lifelong friends, and Livingstone sent his sextant and chronometer readings to Maclear for reduction. Maclear enthusiastically supported measures to improve the well-being of the Cape colony, taking particular interest in the provision of lighthouses, the standardization of weights and measures, and the improvement of hygiene.

After retiring from the observatory in 1870, Maclear went to live at Mobray, near Cape Town. He became blind in 1876. Half a dozen topological features in Cape Province carry his name; a 20-km-diameter lunar crater at 10°.5 N, 20°.1 E is named for him.

Ian Elliott

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Macrobius, Ambrosius (Theodosius)

Flourished **5th century**

Neoplatonist Ambrosius Macrobius's diameter for the Sun (twice the diameter of the Earth) was cited frequently in the Middle Ages. The circuitous derivation of this figure can be read in his *Commentary on the Dream of Scipio*.

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Mädler, Johann Heinrich von

Born **Berlin, (Germany), 29 May 1794**
Died **Hanover, Germany, 14 March 1874**

Johann von Mädler published a celebrated chart of the Moon and the first scientifically based selenography. He was also the author of the first map of Mars, made contributions to stellar astronomy, and compiled a useful history of astronomy.

Mädler was born into the family of a master tailor. Though frail as a child, at the age of 12 he was sent to the Friedrich-Werdersche Gymnasium in Berlin where he received a sound grounding in science and mathematics. His interest in astronomy was inspired by the Great Comet of 1811 (C/1811 F1). Although Mädler was an excellent scholar, he was unable to enter the university at the age of 19. An outbreak of typhus claimed both his parents, so instead of an academic career he considered it his duty to support four younger siblings. He enrolled in the tuition-free Kürstenschen seminary to prepare for a career as an elementary school teacher. At the same time, Mädler began giving lessons as a private teacher. In 1817, he got a job as a schoolmaster of calligraphy, and in 1819, Mädler founded a school for poor children. Meanwhile, he found time to attend lectures at the University of Berlin as an external student. Under the supervision of **Johann Bode**, **Johann Encke**, and Gustav Peter Lejeune Dirichlet (1805–1859), he studied astronomy and higher mathematics. With his enhanced education, Mädler was in a position to give private lessons at a higher level, a turning point in his life.

In 1824, **Alexander von Humboldt** introduced Mädler to the Berlin banker **Wilhelm Beer**, who applied to Mädler for lectures in higher mathematics and astronomy. Attracted by Mädler's lectures, Beer decided to set up his own observatory with Mädler as the main observer. A 97-mm refractor was installed in a small dome in the Tiergarten near Beer's home in 1828. There, Mädler and Beer began one of the more successful collaborations in the history of astronomy.

Mädler and Beer chose to map the surfaces of the Moon and Mars for their first projects. They observed Mars intently during that planet's perihelic opposition in September 1830, made drawings, and attempted to measure the coordinates of the most distinct spots. Their study left little doubt that the markings on Mars were permanent and disproved the previous belief that the spots on Mars were similar to the clouds of the Earth. In 1840 Mädler combined all the observations and drew the first map of Mars ever published. In the opinion of **Camille Flammarion,** Mädler and Beer deserve to be remembered as the true pioneers in this new conquest of Mars, a planet that had been the subject of intense study by "a phalanx of astronomers" for more than a century.

From 1830 to 1836, Mädler and Beer also observed the Moon. Mädler first measured the positions of a network of 106 reference points scattered across the lunar surface with a filar micrometer. Using these benchmarks, Mädler and Beer then measured the positions of 919 lunar formations, the heights of 1,095 mountains, and the diameters of 150 craters. On the basis of these measurements Mädler prepared the first scientifically designed lunar chart, *Mappa Selenographica*, which was published in four parts between 1834 and 1836. In 1837, a descriptive volume *Der Mond, nach zeinen kosmischen und individuellen Verhaltnissen oder allgemeine vergleichende selenography* (The Moon, concerning its cosmic and individual conditions or general comparative selenography) followed. In contrast to most of their predecessors, Mädler and Beer viewed the Moon as an airless, lifeless, and unchanging globe.

It is well known that both in the Mars project and in the lunar mapping and later in preparation of the *Selenograph* Mädler carried out most of the work, the observations, computation, map preparation, and writing. In the lunar-mapping project alone, Mädler spent 600 nights at the telescope. Although some observations were contributed by Beer, his role was primarily that of a patron who made the observatory available to Mädler.

In 1836, primarily because of the favorable reception of the lunar map, Encke employed Mädler as an observer at Berlin Observatory, a welcome relief from his previous occupation as a schoolteacher and part-time astronomer. Probably the best year in Mädler's life, however, was 1840 when he moved to Dorpat, Russia (now Tartu, Estonia) as the director of the observatory and professor of astronomy at the university, replacing **Friedrich Struve** when the latter left to found the Pulkovo Observatory. In the same year, Mädler married a poetess, Minna von Witte.

At Dorpat Observatory, Mädler used the 9-in. Fraunhofer refractor (the Great Dorpat refractor) for micrometric measurements of double stars from the catalog by Friedrich Struve. For 513 binaries he found the presence of orbital motions, for 15 binaries he calculated the orbit parameters. For 3,222 stars with positions observed by **James Bradley** from 1750 to 1762, Mädler found new positions on the basis of meridian observations at Dorpat Observatory and at other observatories, and calculated the proper motions. Subsequently these proper motions were used to study the motions in the stellar universe and to determine the solar motion parameters. Mädler correctly supposed that the motions of stars are governed by the collective gravitational field, but due to rather crude observational data of his time he was mistaken when he found that the center of our stellar system resides in the Pleiades cluster, not far from 180° from the true center of rotation in Sagittarius. In several papers and comments Mädler wrote about the sizes and periods of rotation of the planets.

In Dorpat, Mädler wrote popular books, read popular lectures, and actively contributed to local newspapers, besides doing the ordinary astronomer's work. The director's house near the observatory was a meeting place for literature for local friends. In 1865, Mädler retired from Dorpat University and went back to Germany to live in Wiesbaden, Bonn, and Hanover. In his retirement years, Mädler published an extensive and useful history of astronomy.

Mädler was a member of many scientific societies, the Madrid, Munich, and Wien academies and the Royal Astronomical Society among them. Nevertheless, he was not appointed to the Saint Petersburg academy because his relations with the influential academician Struve were not good. Struve also unsuccessfully opposed Mädler's appointment to the professorship at Dorpat University.

Mihkel Joeveer

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Magini, Giovanni Antonio

Born **Padua, (Italy), 13 June 1555**
Died **Bologna, (Italy), 11 February 1617**

Working at the cusp of Ptolemaic and Copernican astronomy, Giovanni Antonio Magini attempted to combine the best elements of both. Although Magini's theories have traditionally been identified as opposing **Galileo Galilei**'s, there is recent evidence that Magini

supported certain aspects of Galilei's work. Magini's contributions to mathematics and geography were also noteworthy.

Magini completed his early studies in Padua and then attended the University of Bologna, graduating in June 1579 with a degree in philosophy, although he had shown great interest in mathematics since childhood. After **Egnatio Danti** was transferred to Rome in 1587 the Bologna Senate called a competition for the chair of mathematics, which was assigned to Magini in August 1588. The Paduan scientist was chosen over the young Galilei, who had also applied for the chair, not only because of Magini's greater experience and notoriety at the time, but also because he had already published volumes of ephemerides and astronomical tables.

In addition to teaching Euclid, Magini also focused in particular on astrological and astronomical subjects, such as the theory of the planets, and on commentaries to **John of Holywood**'s *Sphaera Mundi* and **Ptolemy**'s astronomy. In 1597 he was given a lifetime teaching position and also received permission to go to Mantua. At the Gonzaga court, in 1599, Magini tutored the children of Duke Vincenzo, for whom he also wrote several astrological opinions. The sterling reputation he had earned among his peers was due also in part to his vast correspondence with all the illustrious scholars of his time, including Galilei, **Tycho Brahe**, and **Johannes Kepler**. Magini established an excellent rapport with Kepler, who in 1610 asked him to come to Prague to work with him on the new astronomical ephemerides. Magini did not accept Kepler's invitation, not only because he and the German astronomer had different viewpoints, but also because he did not want to leave the prestigious chair at Bologna.

According to 19th-century historian Antonio Favaro (editor of the complete edition of Galilei's works), Magini was one of Galilei's most dogged opponents. However, on the basis of recent studies by G. Betti, this view of Magini as Galilei's "enemy" seems exaggerated, particularly since Magini was probably the true author – or at least the direct inspiration – of the 1611 *Epistola Apologetica* against Martin Horky, written in Galilei's defense. Moreover, Magini's two best disciples, Cesare Marsili and Giovanni Antonio Roffeni, were Galilei's most ardent supporters in 17th-century Bologna.

Magini's attitude toward the Copernican system is intriguing. Although he was convinced that the Earth did not move, in some of his works he accepted **Nicolaus Copernicus**' theory as a working hypothesis. He justified this because it simplified calculations and yielded results that better matched observations, even though, in Magini's opinion, the theories were unlikely. Nonetheless, he never agreed with the concept of the Copernican system from a philosophical standpoint, replacing it with his own planetary model that combined the ideas of Copernicus and Ptolemy, and even added several new hypotheses. Magini claimed there was a need for a theory of planets that abandoned the model of the Alphonsine Tables in order to comply with recent observations, but rejected Copernicus' absurd hypotheses. Magini completely changed the Ptolemaic theories of the Sun and the Moon but adhered to the Ptolemaic system for the other five planets, albeit eliminating the equants. Furthermore, he accepted the idea that the stars and planets were pulled by their orbits or spheres and that they could not move independently. He also asserted that there had to be a ninth and tenth sphere between those of the fixed stars and the prime mover. For his theory of the Moon, Magini agreed with Copernicus in affirming that Ptolemaic theory did not comply with observation and experience. He later adopted the cosmological system of Brahe, with whom he established a rapport of both friendship and scientific collaboration. However, he modified the Tychonic system with elements from Kepler's astronomy. Magini defined his new theory in the *Tabulae novae iuxta Tychonis rationes elaborate,* but the work was unfinished when he died and was published posthumously in 1619. However, in 1623, 6 years after Magini's death, the Tribunal of the Holy Office ordered Magini's entire astrological library confiscated.

Magini was far more skilled at calculation than at theory, and the ephemerides he calculated for the years 1581 to 1630 are proof of this. He was a very talented instrument maker. He also wrote *Breve istruzione sopra le apparenze et mirabili effetti dello specchio concavo sferico* on concave mirrors. In 1592, Magini published *Tabula tetragonica sui quadrati dei numeri naturali*, which made it possible to determine the product of two factors, such as the difference between two squares. In 1609, he drew up accurate trigonometric tables in which he introduced new terms for the functions now known as cosine, cotangent, and cosecant. The nomenclature used by Magini attracted several followers and was adopted by **Bonaventura Cavalieri**. Magini also contributed to practical geometry with treatises on the sphere and on the application of trigonometry. He described the use of the quadrant and the astronomical square. Magini was the first person to suggest the use of the decimal point to separate the whole number from the decimals.

Magini was also active in medical astrology. He wrote a commentary on Galen's treatise, confirming that the stars govern the world of nature, and he recommended studying the annual recurrences of nativities and elections, essential for observing when the patient became ill, the critical days in the course of the illness, and the best times to administer medicine.

Magini's importance as a geographer and cartographer is undisputed. His edition of Ptolemy's *Guide to Geography*, which first appeared in Venice in 1596, is extremely important, not so much for Magini's careful descriptive comments but because he added 37 new maps to the 27 Ptolemaic maps, forming a true modern atlas.

However, the work to which Magini devoted most of the latter part of his life was an atlas of Italy, for which he prepared his own maps. Most of them were original and based on official surveys that various Italian governments had done. Because of this work, which Magini funded out of his own pocket, he was perennially in financial difficulty. The definitive compilation of the entire atlas, dedicated to Ferdinando Gonzaga, was published posthumously by Magini's son Fabio in 1620 with the title *Italia di Gio. Ant. Magini data in luce da Fabio suo figliolo*. The work, which had 61 tables and a brief commentary, enjoyed widespread and lasting fame.

Magini was buried in the Church of the Dominicans, with an epitaph dictated by his disciple Roffeni. His chair was offered to Kepler who, in a letter dated 15 May 1617 addressed to the rector of the University of Bologna, regretfully turned down the offer, fearful that as a Protestant he would feel ill at ease in a Catholic environment.

Fabrizio Bònoli

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Mahendra Sūri

Flourished **(India), 14th century**

Mahendra Sūri's *Yantrarāja* (1370) helped to popularize Islamic astronomy in India.

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Maimonides: Abū ʿImrān Mūsā [Moses] ibn ʿUbayd Allāh [Maymūn] al-Qurṭubī

Born **Cordova, (Spain), 1145 or 1148**
Died **Fusṭāṭ, (Egypt), 1204**

Maimonides, the renowned Jewish theologian and physician, also wrote on the relationship between Judaism and the sciences, astronomy in particular. He spent his formative years in Spain and North Africa. He eventually settled in Fusṭāṭ, near present-day Cairo where he achieved his great fame in learning and communal leadership. Nonetheless, Maimonides remained attached to the intellectual outlook of the western part of the Islamic world throughout his life, and this is especially true of his work in astronomy. In his youthful search for guidance, especially in matters of cosmography (which were later to be a major concern), he sought out the son of **Jābir ibn Aflaḥ** as well as some pupils of **Ibn Bājja**. Indeed, his career affords us one of the clearest examples of the distinctive features of the western Islamic astronomical tradition. Maimonides contributed to the Arabic astronomical literature by editing (*i. e.*, preparing corrected versions of texts that had become problematic) books written by two of his Andalusian predecessors, the above-mentioned Jābir and Ibn Hūd, ruler of Seville.

Astronomical issues are stressed at several places in Maimonides' great work of religious thought, the *Guide of the Perplexed*. The most detailed discussion is found in Part Two, Chapter 24, which is devoted entirely to a review of the state of what may be anachronistically called cosmology or celestial physics. Aristotelian physics had established by means of what were then taken to be irrefutable proofs that the motions of the heavenly bodies must be circular, with the Earth at the center. **Ptolemy**'s models clearly violate these principles. All of the solutions that had been offered to date were critically scrutinized and rejected; these included the proposals of **Thābit ibn Qurra** and Ibn Bājja, for which Maimonides remains our only source. Did Maimonides consider the problem insoluble, or to put it differently, did he think the "true configuration" to be beyond human ken? Opinions have differed sharply on this point. It is noteworthy, however, that Maimonides breaks away from some of the Andalusians in that he does not think the solution to lie in rediscovering **Aristotle**'s cosmology. Maimonides firmly believed that astronomy had advanced considerably since Aristotle's day. Although the Stagirite's proclamations in physics remain true, his teachings in astronomy can no longer be maintained. In this respect Maimonides' position is closer to that of the Egyptian **Ibn al-Haytham**.

Maimonides' sole contribution to mathematical astronomy is his procedure for determining the visibility of the lunar crescent, which takes up several chapters of his great law code, the *Mishneh Torah*. Before the calendar was fixed, Jewish law required that the beginning of each month be certified by the court at Jerusalem. No month can exceed 30 days. Hence, if the crescent is not seen on the eve of the 29th, the declaration of the new month is automatic. Maimonides' procedure is necessary only for those instances where witnesses do report a sighting on the eve of the 29th. Specifically, the members of the court need to know whether a sighting is possible, so that they may convene in the expectation of witnesses; and they need a few details about the appearance of the crescent for purposes of cross-examination. Conversely, the court needs to know when a sighting will be impossible, so as to be able to reject any purported sightings.

With these facts in mind, it will be readily understood why Maimonides presents his method in "cookbook" fashion. Solar and lunar parameters, listed by Maimonides, can be plugged in, and the computation is then carried out step-by-step. Eventually the result is a simple yes or no answer; if the answer is yes, some additional information about the appearance of the crescent can be obtained. Theoretical explanations or justifications are kept to a bare minimum. Certain parameters, for example the geographical latitude, are built in, since the computation is meant to be true only for Jerusalem and its environs. Maimonides states that he has allowed himself some approximations, but, he assures us, the round-off errors cancel each other out, so that there is no net effect on the computation.

Maimonides issued some critically important and repercussive statements on the relationship between Judaism and the sciences, astronomy in particular. He asserted that ancient Rabbinic views on the structure of the heavens have no privileged position. The tenets of astronomy can be proven or rejected by universal and invariant rules of logic; hence their source, or, as we might say, the cultural context out of which they emerge, is irrelevant. On the other hand, astronomy is by no means a "secular" science. Knowledge of God, the attainment of which is a primary religious obligation, can be approximated – Maimonides denies that it can be fully achieved – only by inference from creation. The stars are the most noble bodies in creation, and the study of their motions is one of the most religiously fulfilling activities at our disposal.

Y. Tzvi Langermann

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Mairan, Jean-Jacques

Born **Béziers, (Hérault), France, 26 November 1678**
Died **Paris, France, 20 February 1771**

French naturalist Jean-Jacques de Mairan shares credit (1721) with **Henry Cavendish** and John Dalton for accurately determining the height of the aurora. Mairan thought that the phenomenon was caused by zodiacal light particles falling into the Earth's atmosphere.

Alternate name

Dortous de Mairan, Jean-Jacques

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Majrīṭī: Abū al-Qāsim Maslama ibn Aḥmad al-Ḥāsib al-Faraḍī al-Majrīṭī

Born **Madrid, (Spain), first half of the 10th century**
Died **Cordova, al-Andalus, (Spain), 1007**

Maslama al-Majrīṭī was considered by his Andalusian contemporaries as the foremost authority of his time in the field of astronomy. He traveled as a young man to Cordova, the capital of the Umayyad caliphate, where he studied and worked until his death. His achievements are mainly in the field of mathematical astronomy, although it is known that he wrote on commercial arithmetic (*muʿāmalāt*) and was also a renowned astrologer. Historians have at times misattributed to Majrīṭī works on magic and alchemy.

In addition to his own compositions, Majrīṭī's importance lies within the context of Andalusian science and his activity in scientific teaching. Majrīṭī was the founder of an original school of Andalusian astronomers in which the disciplines of arithmetic and geometry were also cultivated. Majrīṭī's disciples, who include outstanding figures like **Ibn al-Samḥ**, **Ibn al-Ṣaffār**, and Ibn Bargūth (died: 1052), spanned three generations and greatly influenced the development and expansion of the exact sciences throughout al-Andalus. Majrīṭī brought together for the first time in al-Andalus two distinct mathematical traditions, namely the tradition of *farā'iḍ* (religiously based division of inheritances) and the tradition of mathematically based philosophical sciences, a category that included astronomy. Majrīṭī's combining of these two mathematical branches reflects the interests of his two known teachers: ʿAbd al-Ghāfir ibn Muḥammad al-Faraḍī, who wrote a treatise on *farā'iḍ*, and ʿAlī ibn Muḥammad ibn Abī ʿīsā al-Anṣārī, who is reported to have known astronomy.

In the field of astronomy, Majrīṭī was the first Andalusian to make his own astronomical observations. According to **Zarqalī**, he observed the star Regulus in the year 979 and found its ecliptical longitude to be 135° 40′. Starting from the determination of the longitude of this star, Majrīṭī was then able to determine the longitude for all fixed stars, thereby establishing a movement of precession of the equinoxes of 13° 10′ with respect to the epoch of compilation of the catalog of stars in **Ptolemy**'s *Almagest*.

The above value for the longitude of Regulus appears in the table of stars that accompanies Majrīṭī's commentary on Ptolemy's *Planisphaerium*, which is a treatise on the stereographic projection of the sphere (the basic technique for the construction of the standard astrolabe). Some historians mistakenly thought that Majrīṭī may have learned Greek and translated the *Planisphaerium* himself, but recent investigation has shown that he most likely revised an eastern Arabic translation of the work. Indeed, Majrīṭī's text contains several additions to the work of Ptolemy that considerably improved the procedures for tracing the fundamental lines of the astrolabe and for locating the fixed stars of its rete, or star map on the instrument, using several kinds of coordinates. In the second part of this work, Majrīṭī deals with a number of problems of spherical astronomy using the Theorem of Menelaus, which was the unique trigonometric tool employed in his time and upon which he had previously written several notes in another work.

Majrīṭī's major work in astronomy was the adaptation that he made, together with his disciple Ibn al-Ṣaffār, of **Khwārizmī**'s *Sindhind zīj*. This 9th century astronomical handbook with tables and explanatory text was based primarily on Indian methods, and thus differed from later Islamic astronomical material, which relied on planetary models laid out in the *Almagest*. Although Khwārizmī's original text appears to be lost, a Latin version by **Adelard of Bath** (12th century) of Majrīṭī's revision is extant. This text, which is referred to as the *zīj* of Khwārizmī-Maslama (Majrīṭī), contains tables derived from Khwārizmī's original *zīj* (which had material based upon Persian and Ptolemaic traditions in addition to Indian ones) as well as material and tables that were adaptations, additions, or replacements introduced by Majrīṭī and Ibn al-Ṣaffār. The aim of the Andalusian astronomers was to adapt the original tables to the time and place in which they were living. For example, the Persian solar calendar used in Khwārizmī's tables was replaced by the Muslim lunar calendar, and some tables that were observer-specific were adapted to the geographical coordinates of Cordova. Khwārizmī's mean motion tables were calculated for radix positions corresponding to the meridian of Arīn (the center of the world in the Indian systems). A significant outcome of using Cordova's longitude was that Majrīṭī provides the earliest evidence of an important correction to the size of the Mediterranean Sea to its actual size; this was preserved in most Andalusian geographical tables. On the whole, the transformations affected the tables for chronology, mean motions, mean conjunctions and oppositions, and visibility of the lunar crescent. They also involved the addition of new tables related to the astrological practices of equating the houses and projecting the rays. Moreover, the contents of the final version of the *zīj* suggest the redactors included some elements that, though not strictly necessary, were in use in contemporary Andalusia. This is the case of the two trigonometric tables that are extant in the Latin translation, one for the sine (based on a radius of 60 parts) and the other for the cotangent (shadow length), which presumably were not used in the original *Sindhind*. Other Andalusian contributions found in the *zīj* are the reference to the Hispanic era (38 BCE) in the chronological part, the use of the meridian and latitude of Cordova for certain tables, and improved calculation methods that were both accurate and easier to use.

As a professional astrologer, Majrīṭī was also interested in the conjunction of Saturn and Jupiter, which took place in 1006/1007; with it he foretold a change of dynasty, ruin, slaughter, and famine.

Josep Casulleras

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Makaranda

Flourished **Kāśī (Vārānasī, Uttar Pradesh, India), 1478**

Makaranda, surnamed Ānandakanda, computed many tables of astronomical phenomena that he published in very useful forms. A reputed astronomer of Kāśī in North India, the hub of intellectual activity in India during medieval times, Makaranda was a follower of the Saura School, one of four principal schools of Hindu astronomy active during the classical period (late 5th to 12th centuries).

Makaranda's work, known simply as *Makaranda*, is an extensive treatise containing many astronomical tables that enable one to read the dates and times of different celestial phenomena. The tables span a large number of years after 1478, when they were commenced. The astronomical phenomena covered by Makaranda are *tithi*s or lunar days, *nakṣatra*s, or asterisms, *yoga*s marking complementary positions of the Sun and Moon, *sam̄krānti*s, or the times of entry of the Sun into the zodiacal signs, the mean motions of the planets and their anomalies, the length of daylight on different days, weekdays, and times of eclipses. As a way of making access to the work easier, Makaranda provided, in certain cases, two sets of tables, one for single years and the other for groups of years.

The labor involved in the preparation of these tables must have been enormous and entailed much ingenuity. But this labor has benefited later generations of astronomers and astrologers by reducing their own time and effort. Makaranda's works are among the most popular in North India, especially at Bihar and Bengal. More than 20 commentaries were prepared on Makaranda's work by later astronomers that explained the principles of construction of the tables and their practical use, which attest to their popularity among the masses.

Ke Ve Sarma

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Makemson, Maud Worcester

Born **Center Harbor, New Hampshire, USA, 16 September 1891**
Died **Weatherford, Texas, USA, 25 December 1977**

Maud Worcester Makemson, astronomy professor and director of the observatory at Vassar College, New York, worked in celestial mechanics and was a pioneering practitioner of archaeoastronomy (especially Polynesian and Mayan astronomy) and astrodynamics (the application of celestial mechanics to spacecraft).

Makemson took up astronomy late in life. Born Maud Lavon Worcester, daughter of Ira Eugene and Fannie Malvina (*née* Davisson) Worcester, she studied classics at the Boston Girls' Latin School (graduating in 1908) as well as at Radcliffe College; eventually she became conversant with Latin, Greek, French, German, Spanish, Italian, Japanese, and Chinese. After a year at Radcliffe, she began teaching in a rural one-room school in Sharon, Connecticut.

In 1911, Worcester moved with her family to a ranch in Pasadena, California. There she met farmer Thomas Emmet Makemson, whom she married the next year (1912), and moved with him to Arizona. By her fifth year of marriage, she had three children: a daughter Lavon (born: 1913) and two sons Donald (born: 1915) and Harris (born: 1917). She had also launched herself into a writing career, becoming a reporter for the *Arizona Gazette* in Phoenix in 1918, and eventually publishing two original plays. In 1919, she and Thomas divorced.

An astronomical spectacle in 1921, however, transformed the direction of Makemson's life. The night of a picnic in the desert north of Phoenix, she was dazzled by a remarkable aurora (widely witnessed throughout the United States on 14 and 15 May), its streamers so bright that they cast enough light to read. The next day, newspapers noted the display had coincided with the appearance of large sunspots. Her curiosity aroused, Makemson began devouring popular books on astronomy. That September, she resigned her newspaper job, moved her children to Palmdale, California (near her parents' home in Pasadena), and supported herself teaching grade school while taking correspondence courses in trigonometry and astronomy from the University of California. In August 1923, Makemson enrolled full-time at the University of California at Berkeley, receiving her BA in 1925 at the age of 34. Over the next 5 years, she earned her MA (1927) and Ph.D. (1930) in astronomy (for work in celestial mechanics under **Armin Leuschner**), receiving several fellowships and research assistantships.

After a year at the University of California as an instructor of astronomy (1930/1931) and another of teaching mathematics and astronomy at Rollins College in Winter Park, Florida (1931/1932), Makemson became an assistant professor of astronomy and navigation at Vassar College. For the next quarter century, Makemson remained at Vassar College , the first astronomy faculty member there not to have been a student of **Maria Mitchell**. By her retirement in 1957, she was director of the college's observatory (from 1936), chair of the astronomy department (from 1941), and a full professor (from 1944).

At Vassar College, Makemson did yeoman work in practical celestial mechanics, calculating the orbits of comets, asteroids, and double stars, as well as teaching astronomy, history of astronomy, and meteorology. She also introduced the heavens to thousands of school children, high-school students, and scout troops who viewed celestial wonders through the observatory's telescopes.

Moreover, Makemson began to spread her intellectual wings farther afield, making use of her knack for languages to pursue what would now be called archaeoastronomy (although her work is not widely cited by archaeoastronomers today). During the summer of 1935, she worked at the Bishop Museum in Honolulu, Hawaii, beginning research on Polynesian astronomy (gaining some contemporary notoriety by suggesting that the legendary star Kokoiki, which allegedly appeared just before the birth of Hawaii's first king, Kamehameha I, might have been Halley's comet (IP/Halley) in 1758). In 1941, Yale University Press published Makemson's book *The Morning Star Rises: An Account of Polynesian Astronomy*, based on the writings of missionaries, Polynesian historians, anthropologists, as well as her own astronomical research (which used her familiarity with Polynesian languages to verify translations of ancient chants).

In 1941 and 1942, Makemson held a John Simon Guggenheim Memorial Foundation Fellowship for the study of Mayan astronomy. Some of her findings were published in 1946 in *The Maya Correlation Problems* (on her attempt at a correlation between the ancient Mayan calendar and the Julian and Gregorian calendars) and in 1951 in *The Book of the Jaguar Priest* (her translation of the Mayan calendar from the original hieroglyphs). In 1953/1954 she was granted a Fulbright Fellowship to teach in Japan.

Upon her retirement from Vassar College in 1957, Makemson returned to California and entered yet her third career, this time in the booming new field of space technology. From 1959 to 1964, she was research astronomer and lecturer at the University of California at Los Angeles [UCLA] and consultant to Consolidated Lockheed-California (1961–1963).

Makemson generally taught positional (navigational) astronomy, and managed to make it seem perfectly natural that a 70-year-old woman should be doing this at a university with no other female faculty in astronomy, mathematics, or physics. Her touch was light, and a characteristic final-examination question said, "you are lost on a desert island with a sextant, chronometer, carrier pigeon and your copy of Smart's *Spherical Astronomy*. Explain how you will save yourself."

At UCLA, Makemson met Robert M. L. Baker Jr., who in 1958 had just received his Ph.D. in engineering, the first of its kind to be granted in the United States with the specialty in astronautics. Although a handful of schools then were teaching astrodynamics – a newly coined word referring to the application of celestial mechanics to spacecraft in orbit around the Earth or on trajectories to the Moon or planets – no textbook on the subject yet existed. Aware of Makemson's experience in celestial mechanics, astronomical history, and book publishing, Baker invited her to coauthor *An Introduction to Astrodynamics*. Over the next decade, their text stood as the only one in the field, going through two editions and multiple printings.

In 1965, in the heyday of the manned space program, Makemson moved to Texas and worked as a consultant to the National Aeronautics and Space Administration [NASA] through the Applied Research Laboratories of General Dynamics in Fort Worth. By 1971, she had devised a technique for the Apollo astronauts to determine their selenographic latitude and longitude by photographing the positions of stars through a zenith telescope, allowing them to navigate around the Moon's surface without radio or radar (although her method does not appear to have been used).

Intellectually active well into her 80s, Makemson's last project was translating *The Astronomical System of Philolaus*, originally published in Latin by **Ismaël Boulliau** in 1645. It was still incomplete at her death in a nursing home. She was survived by one son (who had legally changed his name to Donald Worcester), seven grandchildren, and eleven great-grandchildren.

In addition to her two books, articles by Makemson were published in an eclectic variety of scholarly journals and semipopular magazines, ranging from *American Anthropology* to the *Astronomical Journal* to *The Sky* to the *Bulletin of the Seismological Society of America*.

Trudy E. Bell

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Maksutov, Dmitry Dmitrievich

Born **Nikolayev (Mykolayiv, Ukraine), 11/23 April 1896**
Died **Leningrad (Saint Petersburg, Russia), 12 August 1964**

Dmitry Maksutov was a Soviet optician who is credited as a leading designer of astronomical optical instruments after World War II. A graduate (1913) of cadet school, he was enrolled in the Military Engineering College of Saint Petersburg, but his study was interrupted by World War I. Like other members of his family, he fought in that conflict, and after the 1917 Bolshevik Revolution, attempted to immigrate to the United States through China but failed. Maksutov continued his education at the Tomsk Technical Institute (Siberia) and worked in Saint Petersburg and Odessa, Ukraine, where in 1930 he was arrested but miraculously survived while every other randomly chosen "suspect" was shot. He was arrested for a second time during Stalin's Great Terror in 1937.

From 1930 to 1952, Maksutov worked in the State Optical Institute (Leningrad), where he founded and headed the laboratory for astronomical optics. After 1952, he worked at the Pulkovo Observatory. He was elected a corresponding member of the Soviet Academy of Sciences (1946). On two occasions (1941, 1946), Maksutov was awarded the highest scientific trophy of the USSR, the Stalin Prize, which was renamed the State Prize after Stalin's death. In spite of these honors and his international recognition, Soviet authorities never permitted him to travel abroad.

While not the first to consider melding the best attributes of a refractor and a parabolic reflector, in 1941 Maksutov proposed a meniscus optical system of exceptional performance (the Maksutov telescope). This compact type of a catadioptric telescope differs from the Schmidt design in that the correcting plate is a deeply curved, diverging meniscus lens. Since the primary mirror is also spherical, all three optical surfaces are simple to manufacture. The spherical aberration of the meniscus lens exactly balances that of the primary mirror, yielding a compact and well-corrected optical instrument, though stable and very precise alignment of the optical system is critical. Combining many advantages, Maksutov telescopes became very popular throughout the entire world, although they cannot have a large diameter. American optical engineer John Gregory popularized a variant of this system, foreseen by Maksutov, wherein an aluminized spot on the meniscus lens serves as a Cassegrain secondary. In the United States, a small coterie of amateur telescope makers founded the Maksutov Club, led by Allan Makintosh, and for many years published *Maksutov Club Circulars*.

During the era of slide rules and logarithm tables, Maksutov was actively involved in the design of many astronomical instruments, including the 6-m telescope (then the world's largest) called the Large Altazimuth Reflector [BTA] at the Special Astrophysical Observatory near Zelenchukskaya. He wrote several textbooks on astronomical optics. He is commemorated with a crater on the Moon's farside.

Alexander A. Gurshtein

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Malapert, Charles

Born **1581**
Died **1630**

French astronomer Charles Malapert published one of the earliest drawings of the Moon, as seen through a telescope (1619). A Jesuit, he defended geocentric cosmology against **Galileo Galilei** and Copernican heliocentricity. A lunar crater is named for him.

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Malebranche, Nicholas

Born **Paris, France, 6 August 1638**
Died **Paris, France, 13 October 1715**

Nicholas Malebranche, a prominent natural philosopher who wrote on the metaphysical nature of the Universe, developed a synthesis of Cartesian rationalism with accepted Christian dogma. His replacement of the Cartesian subtle matter with miniature elastic vortices received its most elaborate mathematical treatment in the work of **Johann** and **Daniel Bernoulli**, who attempted to make it consistent with the work of **Johannes Kepler**.

Malebranche was the youngest of 13 children born to the prosperous family of Nicholas Malebranche and Catherine de Lauzon. Because of a spinal condition, he was educated at home until the age of 16. He then moved to the Collège de la Marche, where he received the degree of *Maître ès Arts* in 1656. Malebranche studied theology at the Sorbonne University for the next 3 years and then in 1660 entered the oratory, a papally approved Augustinian order dedicated to reform the Catholic Church from within. He would remain in the order until his death. In 1664 there occurred two events of particular importance in Malebranche's life. He was ordained a priest, and had his first encounter with **René Descartes**' physics. His reading of Descartes' *Traité de l'homme* (*Treatise on man*) would contribute to his adoption of the view that all natural phenomena are to be explained in terms of matter and the laws that govern its motions. In 1669 Malebranche was elected to the Académie royale des sciences for his *Treatise on the Laws of the Communication of Movement*.

A popular move in 17th-century science was to attempt to subsume natural phenomena under general laws. Despite the great success of this in the work of figures like **Isaac Newton**, an issue that still bothered philosophers was the cause of the adherence of bodies to these laws. Some, like the Cambridge Platonists Henry More and Ralph Cudworth, argued that God created immaterial viceregents to keep bodies in line. Even Newton worried about this issue; he flirted with the latter view, also with the view that God Himself acts on bodies to make them adhere to laws. Famously, at the end of the day, Newton opted to "feign no hypotheses" on the issue. Where Newton did not like the metaphysical and theological consequences of the view that God does each and everything, Malebranche embraced them and so was a full-blown occasionalist.

Although he held that God does each and everything, Malebranche did not think that scientific explanations ought constantly to appeal to God's activity. Instead, he argued that they ought to be given in terms of the laws that God has instituted, the laws in accordance with which He constantly acts. Malebranche's view was that since the divine attributes include order and simplicity, God's constant activity is in accordance with general laws. He appears to have been committed to the view that even miracles are in accordance with God's general laws and that we call something a "miracle" when it is anomalous with respect to what we mistakenly take to be the laws in place. (An alternate interpretation has Malebranche committed to the view that God acts in accordance with general laws except when performing miracles.) Nonetheless, Malebranche thinks that in "explaining" a particular event, we should not say that God brings it about; we should instead appeal to the general laws under which it is subsumed. Science, for Malebranche, is the search to uncover these laws. He thus contributed to the tendency in 17th-century science to offer explanations in terms of matter and the laws that govern its motion.

An interesting wrinkle in Malebranche's view arises from a consideration of his deeper metaphysics. He adhered to a representational theory of perception, holding that in sensory perception we perceive objects indirectly *via* our mental representations of them. When we observe an object, we are really just having a mental perception that might or might not correspond to an actual object. Since a perception, like everything else, is caused by God, the question for Malebranche was not whether or not our perceptions correspond to their causes but whether or not there is a material reality that God has created to correspond to these perceptions. In fact, Malebranche held that we cannot know that there are any material objects, except by faith. Malebranche could even hold that the material Universe is perfectly harmonious and orderly. A common maneuver for people like **Johannes Kepler** was to insist on the mathematical order of the Universe even when the astronomical data suggested something less. Malebranche's system allowed him to not take empirical data so seriously. Our perceptions might sometimes be of anomalies and irregularities, but Malebranche could insist that these perceptions do not tell us all about the actual material reality that corresponds to them. Since God's Universe would be maximally perfect and harmonious, Malebranche could ignore unhappy sensory perceptions and hold that our best idealizations of the Universe describe it exactly.

David Cunning

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Mallius

➔ **Manilius [Manlius], Marcus**

Malmquist, Karl Gunnar

Born **Ystad, Sweden, 2 February 1893**
Died **Uppsala, Sweden, 27 June 1982**

Swedish astronomer (Karl) Gunnar Malmquist is eponymized in the Malmquist bias, the idea that a sample of distant objects will inevitably be dominated by the brightest ones, compared to a sample of nearby objects. He wrote down very useful equations for correcting this bias in the early 1920s, although the basic idea was already implicit in earlier work by **Jacobus Kapteyn**.

Malmquist was the son of Emil Vilhelm and Anne Alfrida (*née* Persson) Malmquist. By his first wife, Hanna Karola Gertrud Ingeborg (*née* Lundvall), he had two sons, Sten (a professor of statistics at Stockholm University) and Olle (a medical doctor). Hanna died in about 1951, and a second late marriage to Lisa Malmquist was childless.

Malmquist studied under **Carl Charlier** at the Lund Observatory where he developed methods of mathematical statistics for the analysis of astronomical data, receiving his Ph.D. in 1921. He moved to the Stockholm Observatory in 1931, participating in building the observatory at Saltsjöbaden. Malmquist was appointed professor at Uppsala University in 1939, where he continued his earlier theoretical work on observations of the Milky Way. In addition, he contributed to the founding of the Kvistaberg Observatory and the Uppsala Southern Station on Mount Stromlo in Australia. Malmquist was an active member of the Royal Academy of Sciences in Stockholm, the secretary of Royal Academy of Sciences in Uppsala from 1948 to 1963, and a member of numerous scientific societies.

Malmquist is best remembered for his description of the Malmquist bias, which plays a significant role in both stellar statistics and cosmology and about which an extensive literature exists. The classical Malmquist bias is that using a sample complete to some apparent brightness inevitably yields mean values for any measured quantity that are more and more dominated by the brightest objects at the largest distances. In general this is described by an integral equation incorporating several factors including the line-of-sight density and reddening distributions, the intrinsic properties of the observed sources, and the sensitivity of the detector. The equation has no simple solution. Malmquist showed, however, that under the simplifications of homogeneous space distribution, no absorption along the line-of-sight, and Gaussian distribution of absolute magnitudes with dispersion σ and intrinsic mean of $M\{o\}$, the mean value of $M\{m\}$, for any apparent magnitude m, is related to the intrinsic mean by his well known result:

$$M\{m\} = M\{o\} - 1.382\sigma^2.$$

Different forms of bias plague the measurement of many astronomical quantities, including number counts of sources, estimation of distances, and the motions of galaxies; properly correcting for biases is an important step in gaining knowledge about the Universe. Correct determination of the Hubble constant is particularly sensitive to Malmquist bias.

Other astronomical topics to which Malmquist made significant contributions include the large-scale inhomogeneities of the distribution of bright young stars in the galactic plane and the significance of interstellar absorption outside the plane. The asteroid (1527) Malmquista is named is his honor.

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Ma'mūn: Abū al-ˁAbbās ˁAbdallāh ibn Hārūn al-Rashīd

Born **Baghdad, (Iraq), 14 September 786**
Died **near Tarsus, (Turkey), August 833**

Ma'mūn was the son of Caliph **Hārūn al-Rashīd**, a patron of the arts whose fame has come down to us in the tales of the *Thousand and One Nights*. Hārūn also supported a fine library in Baghdad, called "The Treasure House of Wisdom," as well as the translation of foreign works in various fields. So Ma'mūn, brought up in an educated environment, was not only learned in the traditional Muslim studies but also was aware of a wider world of foreign learning. When he came to the throne as the seventh caliph of the ˁAbbāsid Empire in 813, he was among the well-educated men of his time.

Ma'mūn spent his early years as caliph consolidating his reign and building internal unity in a diverse empire. It has been argued that part of that endeavor involved commissioning Arabic translations of important Persian documents, as part of a project of Arabicizing Persian learning. Since, in addition, many Persian intellectuals believed that Greek learning was in fact based upon older Persian learning, Ma'mūn commissioned translations of Greek material as well. Apart from these political considerations, however, there was undoubtedly a genuine interest on Ma'mūn's part in the learning of the Greeks. There is also a story of a dream in which Ma'mūn saw the Greek sage, **Aristotle**, reassuring him that religion and learning were not enemies and that Ma'mūn's support of foreign learning was not a threat to Islam.

Ma'mūn was zealous in his search for new material and sent the scholar Salm to Byzantine lands to buy manuscripts. (Salm also helped to improve an Arabic translation of **Ptolemy**'s astronomical classic, *The Almagest*.) According to some reports Ma'mūn founded, in the early 830s before his death, the Bayt al-Ḥikma, the House of Wisdom. However, some historians have argued that this was less a new foundation than an extension of the Treasury of Wisdom that was already in existence at the time of Hārūn. In any case we do know that Ma'mūn supported scholars of many nations and professing many faiths, who studied, translated, and disseminated wisdom and learning, particularly that of the Greeks.

In addition to his general interest in the learning of the ancients, part of Ma'mūn's support for astronomy was based on its utility for astrology, a subject with which it was to be closely associated for many centuries. Whatever the motives for his support, the result of these translation efforts was the translation into Arabic of a number of Greek astronomical works. These included the introductory treatises of **Theodosius,** Euclid, **Menelaus,** and **Aristarchus**, as well as all of Ptolemy's works.

In addition to supporting the intellectual climate in which this work could be done, Ma'mūn also sponsored two sets of observations. The first was done in Baghdad, in 828, in the Shammāsiyya area, by astronomers including **Yaḥya ibn Abī Manṣūr** and the noted mathematician **Khwārizmī**. (Two others were **Sanad ibn ˁAli** and **ˁAbbās al-Jawharī**.) The Shammāsiyya observations were conducted around the times of the solstices and equinoxes, and it appears that Ma'mūn took an active interest in them. **Bīrūnī** informs us in his *Taḥdīd* that Ma'mūn rejected the first set of observations of 828 because of the big difference between the values for the maximum and minimum altitudes of the Sun (at the summer and winter solstices, respectively) at those observations and at the latter ones.

Yaḥya died before Ma'mūn left on one of his campaigns against the Byzantines in the early 830s. After his death, Mā'mūn decided to do new observations at Dayr Murrān on a hill near Damascus. Accordingly, he charged **Khālid ibn ˁAbd al-Malik al-Marwarrūdhī** with the task of doing observations over the period of a year with a new set of instruments. The observations, done in two periods between 831 and 833, lasted more than a year. They pleased Ma'mūn sufficiently for him to order that astronomical tables be prepared on the basis of their results. Since the observations both in Damascus and Baghdad seem to focus entirely on the Sun and Moon, these tables must have reflected earlier material for planetary motions.

Quite apart from these undoubted contributions to astronomy, Ma'mūn furnished an example of the type of a ruler that found many echoes in medieval Islam. The result was the development of the observatory as a new scientific institution, a development directly inspired by Ma'mūn, and, more generally, a tradition of royal patronage of astronomy.

Len Berggren

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Manfredi, Eustachio

Born **Bologna, (Italy), 20 September 1674**
Died **Bologna, (Italy), 15 February 1739**

Eustachio Manfredi, a skilled observer of the heavens, a geographer, and a geodesist, oversaw the restoration and continued development of astronomy in Italy following the departure of **Giovanni Cassini** to Paris.

The son of Alfonso Manfredi, a notary from Lugo di Romagna, and Anna Maria Fiorini, Eustachio was the eldest of a family of scholars devoted to science and mathematics. Manfredi completed his early studies at the Jesuit school in Bologna, focusing on philosophy. In 1692, he graduated with a degree in civil and canon law, but never practiced. At Bologna, Manfredi studied mathematics and hydraulics with Domenico Guglielmini, and together with his childhood friend Vittorio Francesco Stancari, he became interested in astronomy.

After Cassini left for Paris and **Geminiano Montanari** for Padua, Italian astronomy in universities faded. Lecturers focused mainly on hydraulics and the science of numbers, and few studied astronomy. Cassini's meridian line of San Petronio was no longer in use. Manfredi and Stancari—who were essentially self-taught—conducted observations with the meridian, and at Stancari's house they set up a small observatory with a sextant and several telescopes. From 1698 to 1702, they undertook systematic observations of the relative positions of stars; studied planetary movements; and observed lunar and solar eclipses, the eclipses of Jupiter's satellites, and lunar occultations—doing so to determine accurately Bologna's geographical position.

In 1690, Manfredi, Stancari, and others, including the famous physician Giovanni Battista Morgagni, founded the *Accademia degli Inquieti*, which became a driving force for Bolognese culture. The institution turned its attention to the physical sciences, studying new systems such as those of **René Descartes**, **Gottfried Leibniz**, and **Isaac Newton**, focusing in particular on experimental and observational reality. The Accademia contributed decisively to the establishment of the *Istituto delle Scienze*, founded by Count Luigi Ferdinando Marsili, a member of one of Bologna's most illustrious families. Marsili, a valiant general and a scientist, believed that scientific research was the cornerstone of technological progress. His military experiences gave him opportunities to collect scientific and documentary material in order to establish a center in Bologna. Astronomy played a predominant role in the Accademia, representing the basic element of reform for a scientific alternative to Aristotelian thought; as a result, in 1702 Marsili appointed Manfredi and Stancari to oversee the construction of an observatory in Bologna, in his own *palazzo*. Instruments were ordered from the Lusverg family in Rome: two movable quadrants, a mural semicircle (currently exhibited at the Astronomical Museum of the University of Bologna), and a 3-ft. telescope.

During this period, Manfredi also studied sunspots, noting that there were far fewer than those observed by earlier astronomers. This phenomenon is now referred to as the Maunder minimum. In 1703, Manfredi wrote a pamphlet entitled *Descrizione d'alcune macchie scoperte nel Sole*, publishing his observations, from which he also calculated the value of the inclination of the rotational axis of the Sun on the ecliptic. In 1699, he was appointed lecturer in mathematics, and in 1704 he was appointed rector of a Pontifical College and was named Superintendent of Waters, a position he held until his death.

In 1712, Marsili donated all his instruments and his collections to the Bologna Senate, and on 13 March 1714, with the financial support of Pope Clement XI, the Istituto delle Scienze was inaugurated in Palazzo Poggi (now the seat of the University of Bologna). The Istituto incorporated the Accademia, with the name Accademia delle Scienze, and the Accademia delle Belle Arti. Manfredi was one of the inspirers of the institute and, in drawing up its program, he looked to Cassini, with whom he corresponded. A new observatory alongside the Istituto delle Scienze was planned, and construction began in 1712 under Manfredi's supervision, but was not completed until 1725; the main instruments were installed in 1727.

In 1715 Manfredi compiled the *Bolognese ephemerides* for the years 1715–1725, based on Cassini's tables, completed in Paris and previously unpublished. They included tables of the planets' transit time across the meridian, the eclipses of Jupiter's satellites, and the lunar conjunctions, as well as maps of the regions on Earth where solar eclipses would take place. The *Ephemerides*, considered among the best in Europe for several decades, were accompanied by a valuable book of instructions, *Introductio in Ephemerides,* detailing their use. The ephemerides for the period of 1726–1750 were subsequently published in 1725.

At this time, with the help of several assistants, including his two sisters, Manfredi undertook systematic observations to verify if there were perceptible shifts in the positions of the stars. If observed, these displacements would allow him to measure stellar parallax and confirm the Earth's annual revolution around the Sun; the issue of heliocentric and geocentric systems was still being debated. The initial observations revealed small shifts in the positions of the stars, yet they were not attributable to the parallactic displacement. The results were published in 1729 in *De annuis inerrantium aberrationibus*. That year, **James Bradley** offered the correct explanation for this phenomenon, later called "annual aberration of starlight," after the title of Manfredi's publication. Two years later, in Tome I of the *Commentarii dell'Accademia delle Scienze*, Manfredi published a treatise entitled *De novissimis circa fixorum siderum errores observationibus*, adding other observations to those of Bradley. Manfredi was the first to confirm Bradley's hypotheses. He did not explicitly express an opinion that would link him too closely to Bradley's explanations, due to the local political and religious situation. (Bologna was part of the Papal States.) Nevertheless, it was the first evidence of the Earth's movement around the Sun.

In 1736 Manfredi published *De gnomone meridiano Bononiensi ad Divi Petronii*, in which he included the history and description of Cassini's meridian, as well as all observations made since the instrument was created in 1655. His analysis of nearly 80 years of observations revealed a progressive decrease of one second per year in the obliqueness of the ecliptic. Although the actual value is approximately half a second, this nevertheless revealed and measured – for the very first time – a process that if continues unchanged would abolish the seasons in less than 2,000 centuries.

The following year Manfredi oversaw the publication of **Francesco Bianchini**'s *Astronomicae ac geographicae observationes selectae*. He had also previously organized and completed Stancari's notes, published as *Schedae mathematicae et observationes astronomicae*. His university lectures were collected into a considerable work, *Instituzioni astronomiche*, published posthumously in 1749.

In 1738 Manfredi asked Jonathan Sisson to make a new set of instruments. However, the astronomer died 2 years before the instruments were delivered. Sisson's instruments, installed and used by Manfredi's successor **Eustachio Zanotti**, are also exhibited at the Astronomical Museum. Because of his scientific merit, Manfredi was honored as a member of the Paris Académie des sciences and London's Royal Society.

Manfredi's manuscripts and the astronomical logbooks are in the Historical Archive of the Department of Astronomy, University of Bologna.

Fabrizio Bònoli

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Manilius [Manlius], Marcus

Flourished **Rome, (Italy), 10**

Marcus Manilius, a citizen of Rome, authored *Astronomicon libri V*, the oldest and most widely cited work on ancient astrology. Nothing certain is known of his life, education, or related writings. Rediscovered in the Renaissance, the *Astronomica* soon developed a wide audience and an unparalleled tradition of scholarly editors, among them the foremost astronomers of their day. For the average reader, the *Astronomica* served as a literary introduction to the heavens and an advanced primer to astrology. Manilius' masterpiece, a Latin didactic poem in five books, unveils the cosmos in hexameter verse, explaining the celestial sphere and zodiac, "describing the stars, constellations, and planets," and above all, providing a Stoic vision of the celestial dance. It is not an introduction to astronomy – here even the basics are sometimes confused – and, indeed, astrological doctrine is often muddled. More significantly, the heavens for Manilius were a reminder to persist against fate, to trust divine reason. Influenced by **Ovid** and **Virgil**, Manilius opposed **Lucretiu**s' harsh view of civil society. For subsequent scholars, the *Astronomica* was an elegant and influential text, albeit beset with a bizarre style and complex history.

The traditional difficulty with the *Astronomica* stems from the absence of an archetype text and an abundance of corrupt copies. The longstanding debate concerning Manilius' manuscripts (and indeed the identity of the author) extends back to the 10th century, although it is now clear that Manilius lived during the reign of Augustus and Tiberius, and probably wrote the *Astronomica* between 14–27. The debate widened with the advent of the printing press (*circa* 1450), and since that time the *Astronomica* has had a remarkably rich publication history. The first notable printing (*circa* 1472) came from the celebrated Renaissance astronomer, **Johann Müller** (Regiomontanus), and by 1650 nearly a dozen printings had appeared. The first firm textual basis for the *Astronomica* was provided by the French scholar, J.-J. Scaliger (1540–1609), whose *Astronomica* (1579; Heidelberg 1590) was later reprinted by Johann Heinrich Boecler (1611–1672) in Strasbourg (1655) with commentary by the French astronomer **Ismaël Boulliau**.

Thereafter, interest in Manilius spread as the New Science took root in the Republic of Letters. Gerhard Vossius (1577–1649) and his son, Isaac Vossius (1618–1689), for example, corresponded with Boulliau (and others in his circle), each contributing to Manilius studies. This group included J.-F. Gronovius (1611–1671), Nicolaas Heinsius (1620–1681), Claude Saumaise (1588–1653), P.-D. Huet (1630–1721), and Edward Sherburne (1618–1702), professor of astronomy at Oxford. Sherburne's first English translation of Book I (*The Sphere*, London, 1675) was soon followed by the first complete English translation (Books I–V, London, 1697; 1700) published by Thomas Creech (1659–1700), also from Oxford. The Creech editions underwent several large printings and launched the modern popular tradition.

The modern scholarly tradition of the *Astronomica*, however, stems from Richard Bentley, the foremost classical scholar of his day, and here again classical studies and the New Science converged. Bentley's interest in Manilius began five decades before he published his *Astronomica* (London, 1739), and two years before he initiated his famous "Newton–Bentley Correspondence" (1692–1693). If that exchange epitomized Enlightenment it also echoed Antiquity. Ironically, Manilius' pagan concerns – Reason, Nature, Design – resonate throughout Bentley's "Confutation of Atheism" (1693), both texts claiming that the World was not a "fortuitous or causal concourse of atoms."

Two final editions of Manilius must be noted. As the Enlightenment drew to a close, the French astronomer **Alexandre Pingré**, celebrated for his work on comets, published an elegant edition of the *Astronomica* in Latin and French. The dean of Manilius scholars, however, is A(lfred) E(dward) Housman (1859–1936), the noted British poet, whose edition of the *Astronomica* is painstaking and pure. The best source for the modern reader, at once rigorous and readable, is edited by G. Goold.

Robert Alan Hatch

Alternate name

Mallius, Marcus

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Mañjula

➔ **Muñjāla**

Maraldi, Giacomo Filippo

Born **Perinaldo near Imperia, (Liguria, Italy), 21 August 1665**
Died **Paris, France, 1 December 1729**

As one of the earliest members of the Paris Observatory staff, astronomer and geodesist Giacomo Maraldi, sometimes identified as Maraldi I, conducted the first systematic observations of the surface features of Mars. The son of Francesco Maraldi and Angela Cassini (sister of **Giovanni Cassini**), Maraldi studied near his hometown until 1687 when, at his uncle's request, he moved to Paris and joined the observatory staff as an observer. Maraldi's main task was the production of a new stellar catalog that remained incomplete on his death; it was never published. He appears to have been a careful observer and was certainly a mainstay in the observatory's work. Maraldi observed a wide variety of phenomena, including planets, satellites, eclipses, and variable stars (including the discovery of R Hydrae). He observed six comets, calculating several orbits. It was he who first realized that the corona belongs to the Sun, not to the Moon.

Maraldi supported his uncle in the controversy with **Ole Römer** concerning the velocity of light, which the latter believed to be finite. Römer's theory, which he used to account for discrepancies between predicted and observed times of eclipses and occultations for the Galilean satellites of Jupiter as observed from Earth at various times of the year, was later shown to be correct.

One of Cassini's programs was a geodesic survey of France. Maraldi was brought into the operation to extend the Paris meridian south, working with **Jacques Cassini** (Cassini II), J. de Chazelles, and Pierre Couplet during 1701/1702. In 1718, he assisted in a survey of the Paris–Amiens meridian to Dunkirk with Cassini II.

During 1702/1703, Maraldi resided in Rome, where he worked on producing a meridian for the Church of the Carthusians and making observations.

Maraldi is best remembered for his Mars observations. He observed Mars at every opposition from 1672, eventually determining a rotational period of 24 hours 40 m. On the surface, Maraldi identified what later became named as Syrtis Major, Mare Sirenum, and Mare Tyrrhenum. He also monitored the polar caps. Late in his life Maraldi brought his nephew, **Giovanni Maraldi**, onto the Paris staff. Maraldi was associated with the Paris Academy of Sciences from 1694.

Richard A. Jarrell

Alternate name

Maraldi I

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Maraldi I

➜ **Maraldi, Giacomo Filippo**

Maraldi, Giovanni Domenico [Jean-Dominique]

Born **Perinaldo near Imperia, (Liguria, Italy,) 17 April 1709**
Died **Perinaldo near Imperia, (Liguria, Italy), 14 November 1788**

As an observational astronomer at the Paris Observatory, Giovanni Domenico Maraldi made an accurate determination of the difference in longitude to the Greenwich Observatory and contributed important observations of comets and nebulae. He was related, though somewhat indirectly, to the famed Cassini family and the great astronomer **Giovanni Cassini** – indeed it seems he was likely named after his famous relative. But the Cassini family produced at least six astronomers and one somewhat well known botanist between the mid-17th century and the mid-19th century with no fewer than three using the name Giovanni Domenico or Jean Dominique (depending on whether the individual lived in France or Italy). Giovanni Maraldi was sometimes referred to as Maraldi II and was the nephew of **Giacomo Maraldi** (Maraldi I), who was, in turn, the nephew of Giovanni Cassini.

Maraldi II came to Paris in 1727 from his home, also the birthplace of his uncle and of Cassini. Perinaldo, though in Italy, was a mere 55 km from Nice, France. In 1731, Maraldi II was made a member of the Paris Academy of Sciences and was employed at the Paris Observatory, then home of his uncle Maraldi I and of several of the younger members of the Cassini clan including his cousin **Jacques Cassini**, with whom he performed some of his most memorable observations. Maraldi II retired in 1772 and returned to Perinaldo. There is actually mention of yet a third Maraldi (Giovanni Filippo: 1746–1797), sometimes referred to as Maraldi III, who observed planetary satellites at Perinaldo, but only one obscure source makes this reference.

When Maraldi II first arrived in Paris he was assigned the task of carrying out geodesic measurements using the eclipse times of Jupiter's satellites. Using this technique, he found a longitude difference between Paris and Greenwich of 9 min 23 s compared to the modern value of 9 min 20.93 s. Later Maraldi was to observe several comets, starting in 1742 and including the great comet of 1743/1744 (discovered by Dirk Klinkenberg and **Jean-Philippe Loys de Chéseaux**). Maraldi II also observed Halley's comet (IP/Halley) in 1759 and calculated several comet orbits. When not observing comets Maraldi observed the transits of Mercury and Venus and helped to publish 25 volumes of the *Connaissance des Temps* and **Nicolas de La Caille**'s catalog of southern stars, *Coelum Australe Stelliferum*. In September 1746, he observed comet C/1746 P1 De Chéseaux (which had been discovered by Loys de Chéseaux) along with his cousin Jacques Cassini. In the process of observing this comet, Maraldi discovered two globular clusters that would eventually be included in **Charles Messier**'s historic catalog: M2 in Aquarius and M15 in Pegasus.

Ian T. Durham

Alternate name

Maraldi II

Selected Reference

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Maraldi II

Maraldi, Giovanni Domenico [Jean-Dominique]

Marius

Mayr, Simon

Markarian, Beniamin Egishevich

Born **Shulaver, (Armenia), 29 November 1913**
Died **Yerevan, (Armenia), 29 September 1985**

Armenian observational astronomer Beniamin Markarian is remembered for the discovery of many hundreds of galaxies, the Markarian galaxies, characterized by more emission in the ultraviolet [UV] part of the spectrum than found in normal spirals or ellipticals. Many of them also have compact nuclei and are related to the quasars. Mkn 421 was the first object outside the Milky Way recognized as a source of photons as energetic as teraelectron volts.

Markarian graduated with a degree in mathematics from Yerevan State University in 1938 and began postgraduate work with **Viktor Ambartsumian,** defending his thesis in 1944 and beginning work with Ambartsumian at the Byurakan Astrophysical Observatory, where he remained until his death. He was elected to the Armenian Academy of Sciences in 1971, received a state prize in 1950, and served as president of the Commission on Galaxies of the International Astronomical Union (1976–1979), in which position he was eventually succeeded by his close colleague Edward Khachikian (1991–1994).

Markarian's early work was in spectroscopy, at relatively high resolution, of white dwarfs and stars in open clusters. But in 1965 Ambartsumian asked him to take over a project that was to obtain low-resolution (objective prism) spectra of a very large numbers of galaxies to look for faint blue ones with strong UV emission. Ambartsumian expected that these would be related to Seyfert and other active galaxies and fit into his (now obsolete) model that indicated diffuse material in the Universe, including gas and star clusters, was initially expelled from much denser material at galactic centers. Markarian primarily used an objective prism with an angle of 1.5° (producing a dispersion of about 2000 Å/mm) at the prime focus of the 1-m Schmidt telescope at Byurakan. By 1967 he had compiled a list of 70 UV-excess galaxies, eventually examining more than 2,000 plates, covering 17,000 square degrees of the sky and containing about 15,000 objects per plate. The final list of objects with strong UV continua took the numbers up to about 1,500. A second spectroscopic survey was begun by Markarian and his Byurakan colleagues in 1978; he continued to participate in the discovery and characterization of new Seyfert galaxies and quasi-stellar objects until his death. Markarian never traveled outside the Soviet Union, and some of the follow-up spectroscopy was carried out at Mount Palomar by his colleague Khachikian, who has continued work on UV galaxies since Markarian's death. Many of the objective-prism images from the 1960s were recorded on Kodak spectroscopic plates imported into Armenia with considerable difficulty.

Ian T. Durham

Acknowledgment

The author gratefully acknowledges Professor Edward Khachikian for providing most of the information on Markarian.

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Markgraf, Georg

Born **Liebstadt near Dresden, (Germany), 30 September 1610**
Died **São Paulo de Loanda, (Angola), 1643 or 1644**

Naturalist Georg Markgraf made the first systematic astronomical observations of the southern skies. At the age of 16, Markgraf began a tour of Central European universities including Strasbourg, Basle, Ingolstadt, Altdorf, Erfurt, Wittenberg, Leipzig, Griefswald, Rostock, and Stettin, before finally matriculating at the University of Leiden in September 1636. Markgraf officially studied medicine. One of his instructors there was Jacob Gool, the noted astronomer and arabist. Another Leiden astronomer, Samuel Kechel, was also a close associate. By June 1636 Markgraf was in Brazil, where he was to remain for the next 8 years, probably in the employment of Johan Maurits van Nassau-Siegen, who was expanding Dutch interests in South America. Markgraf busied himself in compiling detailed maps of the region, collecting specimens of flora and fauna, and making astronomical observations.

Markgraf's astronomical ambition may have been to become a New World equivalent of **Tycho Brahe**. Establishing an observatory in the Vrijburg Palace at Mauritsstad, he was almost certainly the first European to pursue systematic astronomy in the Southern Hemisphere. Markgraf recorded the meridian altitudes of stars and planets as well as a solar eclipse (13 November 1640) and a lunar eclipse (4 April 1642). He planned a treatise to be entitled *Progymnastica mathematica Americana* – intriguingly similar to Brahe's *Astronomia insauratae progymnasmata* – but apparently never produced as much as a rough draft. Sometime after August 1643 Markgraf left Brazil for São Paulo de Loanda in Angola, a new Dutch possession in Africa, where he soon contracted a tropical fever and died. Johan de Laet acquired Markgraf's natural history papers; this valuable material was published in *Historia naturalis Brasiliae* (1648). Markgraf's astronomical observations and calculations, including those for some 26 horoscopes, remain unpublished in collections of the Gemeentearchief (Municipal Archives) Leiden and the Observatoire de Paris.

Keith Snedegar

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Markov, Andrei Andreevich

Born **Ryazan, Russia, 14 June 1856**
Died **Petrograd (Saint Petersburg, Russia), 20 May 1922**

Russian mathematician Andrei Markov had the good luck to work with Pafnuty Chebyshev (of the polynomials) at Saint Petersburg (1874–1878). Many of his contributions were in the area of probability theory, including a refinement of the central limit theorem invented by **Pierre de Laplace**. He is best known for the Markov chains. Roughly these describe systems and processes whose future can be predicted from (completely known) current conditions with no knowledge of the past history of the system. Some astronomical systems, for instance clusters of stars (treated as point masses), can be thought of as Markovian. In practice, the precise knowledge of everything about the system at one time is never available. Markov's contemporary A. Lyapunov wrote down criteria for deciding when imprecise knowledge of a system would lead to its future behavior evolving in totally unpredictable directions. Such systems are called chaotic and can be recognized by the so called Lyapunov exponent.

Virginia Trimble

Selected Reference

Anon. (1994). "Markov." In *The Biographical Dictionary of Scientists*, edited by Roy Porter, 2nd ed., p. 462. New York: Oxford University Press.

Markowitz, William

Born **Mlec, (Austria), 8 February 1907**
Died **Pompano Beach, Florida, USA, 10 October 1998**

William Markowitz devoted most of his career to improving astronomical measurements for determining time, and then to establishing new time systems based on atomic standards rather than astronomical measurements. His efforts, as director of the United States Naval Observatory [USNO] Time Service Department, resulted in greatly improved international cooperation on matters related to time.

Markowitz was the son of Hyman and Rebecca (*née* Baumstein, from Poland) Markowitz. In 1910, he immigrated with his family to Chicago, Illinois, USA. His early interest in astronomy developed at Crane Technical High School in Chicago and Crane Junior College, where Markowitz took a course in astronomy. He entered the University of Chicago and obtained his B.S. (1927), M.S. (1929), and Ph.D. in astronomy (1931). Markowitz married Rosalyn Shulemson in 1943; they had one son, Toby.

After teaching at Pennsylvania State College, Markowitz joined the USNO in 1936, working under Paul Sollenberger and with **Gerald Clemence**. He later served as director of the USNO's Time Service Department from 1953 until his retirement in 1966. Markowitz's principal research interests concerned the rotation of the Earth and the motion of its pole. The polar motion occurring at decadal time scales is named the Markowitz wobble for him.

One of Markowitz's early duties was operating the Photographic Zenith Tube [PZT]. In 1949, he and Sollenberger designed an improved version for the observatory's new station near Miami, Florida. The variation of latitude, determined with the PZT, was one of Markowitz's chief research interests. Analysis of these data led to his contributions on the study of polar motion.

Markowitz directed the Time Service Department during a period of increasing demands for more uniform and accurate time. Ephemeris time, based on the orbital motion of the Earth, was proposed in the early 1950s to provide a more uniform time scale than that based on the Earth's rotation. Markowitz devised a practical means for its determination by inventing the dual-rate Moon camera bearing his name. The first Markowitz Moon camera was placed in operation at the Naval Observatory in June 1952, and 20 such cameras were used around the world during the International Geophysical Year (1957/1958). With data from these cameras, Markowitz worked with Louis Essen at the National Physical Laboratory in England to calibrate newly developed atomic clocks in terms of the Ephemeris second. The fundamental frequency of cesium atomic clocks, 9,192,631,770 Hz, which they determined, has defined the "second" internationally since 1967. At the International Astronomical Union [IAU] meeting in Dublin in 1955, Markowitz proposed the system of UT0, UT1, and UT2, which went into effect within months and remains today.

Markowitz participated in experiments synchronizing time using artificial satellites and atomic clocks transported by airplanes. He served as president of the IAU Commission on Time from 1955 to 1961, and was active in the International Union of Geodesy and Geophysics, the American Geophysical Union, and the International Consultative Committee for the Definition of the Second.

After retiring from the Naval Observatory, Markowitz served as professor of physics at Marquette University (1966–1972), and adjunct professor at Nova University in Florida.

Steven J. Dick and *Dennis D. McCarthy*

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Dick, Steven J. and Dennis D. McCarthy (1999). "William Markowitz, 1907–1998." *Bulletin of the American Astronomical Society* 31: 1605.

Marrākushī: Sharaf al-Dīn Abū ˁAlī al-Ḥasan ibn ˁAlī ibn ˁUmar al-Marrākushī

Flourished **(Egypt), second half of the 13th century**

Marrākushī was one of the major astronomers in 13th-century Egypt. As his name indicates, he was originally from Maghrib, but his major astronomical activities took place in Cairo during the second half of the 13th century. It is not too surprising, given the turmoil affecting al-Andalus and Maghrib at that time, that a scholar from the westernmost part of the Islamic world would decide to emigrate to Egypt, whose capital Cairo was already established as the major cultural center of the Arab–Islamic world. Unfortunately, Marrākushī does not figure in any biographical sources, so we must rely on the scanty evidence provided by his own work in order to shed some light on his life.

Marrākushī is best known for his remarkable *summa* devoted to spherical astronomy and astronomical instrumentation, entitled *Jāmiˁ al-mabādi' wa-'l-ghāyāt fī ˁilm al-mīqāt* (Collection of the principles and objectives in the science of timekeeping), which is intended as a comprehensive encyclopedia of practical astronomy. This work is the single most important source for the history of astronomical instrumentation in Islam. It was the standard reference work for Mamluk Egyptian and Syrian, Rasūlid Yemeni, and Ottoman Turkish specialists of the subject.

This voluminous work (most complete copies cover 250 to 350 folios of text, diagrams, and tables) has occasionally been qualified as a mere compilation of older sources without original contents. While it is true that this synthetic work heavily depends upon the works of predecessors, it is definitively original and without any precedent. In fact, no single part of the work can be proven to reproduce the words of an earlier author, except for the few sections where Marrākushī clearly states from whom he is quoting. In those occasional cases where an earlier source is mentioned, Marrākushī's text always turns out to be either a major rewriting of the original or an independent paraphrase.

The *Jāmiˁal-mabādi' wa-'l-ghāyāt* is well written and logically organized, and employs a relatively literate style that is unusual for a work on technical topics. The author is clearly a very competent astronomer and also occasionally displays his knowledge of ancillary disciplines such as philosophy.

The *Jāmiˁ* is made up of four books on the following topics:

(1) On calculations, in 67 chapters. This book gives exhaustive calculatory methods (without proofs) concerning chronology, trigonometry, geography, spherical astronomy, prayer times, the solar motion, the fixed stars, gnomonics, *etc.*
(2) On the construction of instruments, in seven parts. The first part concerns graphical methods in spherical astronomy and gnomonics. The second through the seventh parts then treat the construction of portable dials, fixed sundials, trigonometric and horary quadrants, spherical instruments, instruments based upon projection, and observational and planetary instruments.
(3) On the use of selected instruments, in 14 chapters.
(4) The work ends with a "quiz" – *i.e.*, a series of questions and answers – in four chapters, whose aim is to train the mental abilities of the students.

An interesting confirmation of Marrākushī's Maghribi origin is provided by his geographical table: 44 of the 135 localities featured in the list of latitudes are written in red ink to indicate that the author visited these places personally and determined their geographical latitude *in situ* through observation. These 44 locations begin along the Atlantic coast of today's western Sahara, include numerous cities and villages in the Maghrib, two cities in al-Andalus (Seville and Cádiz), and continue along the Mediterranean coast *via* Algiers, Tunis, and Tripoli to end up in Alexandria, Cairo, Minya, and Tinnis. Marrākushī's western Islamic heritage is also apparent in the fact that his chapters on precession and solar theory depend upon the works of **Zarqālī** and **Ibn al-Kammād**.

Marrākushī appears to have written his major work in Cairo during the years 1276–1282. First, a solar table is given for the year 992 of the Coptic calendar (Diocletian era), corresponding to the years 1275/1276. Also, some examples of chronological calculations are given for the year 1281/1282, and his star table in equatorial coordinates is calculated for the end of the same year.

The arrival of Marrākushī in Cairo coincided with the establishment of the first offices of *muwaqqits* (timekeepers) in Egyptian mosques. His work can thus be seen as fulfilling a specific demand of Mamlūk Egyptian society (more specifically, the mosque administration, the muezzins and *muwaqqits*, instrument-makers, interested students, *etc.*). But the lack of any reference to the profession of the *muwaqqit* or to the milieu of the mosque would seem to indicate that Marrākushī was an independent scholar without institutional affiliation. The motive he gives for writing his *magnum opus* is the inadequate education of instrument–makers and their methodological failures. His introduction suggests that his target audience was instrument–makers, *i.e.* artisans and practitioners of applied science, who were not professional astronomers. However, this is somewhat contradicted by the technical level of the book, which certainly assumes the reader to know at least the basics of arithmetic, geometry, spherics, algebra, and trigonometry. Thus the *Jāmiˁ al-mabādi' wa-'l-ghāyāt* seems more likely to be a comprehensive reference work of intermediate to advanced level intended for active and apprentice *muwaqqits*, and for specialists of timekeeping and instrumentation who were associated with them.

Marrākushī must have died, most probably in Cairo, between the years 1281/1282 and *circa* 1320, since two early 14th-century sources refer to him as being deceased (an anonymous treatise on timekeeping entitled *Kanz al-yawāqīt*, datable to 723 H/1323 and preserved in MS Leiden Or. 468, f. 91r, and a treatise on instrumentation by **Najm al-Dīn al-Miṣrī** composed in Cairo *circa* 1330).

François Charette

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Martin of Bohemia

➜ **Behaim, Martin**

Martinus Hortensius [Ortensius]

➜ **Van den Hove, Maarten**

Marwarrūdhī: Khālid ibn ʿAbd al-Malik al-Marwarrūdhī

Flourished **Damascus, (Syria), 832**

Along with **ʿAlī ibn ʿĪsā al-Asṭurlābī** and a party of surveyors, Khālid ibn ʿAbd al-Malik al-Marwarrūdhī traveled to the Plain of Sinjār under orders of ʿAbbāsid Caliph **Ma'mūn** to determine the size of the Earth by making accurate measurements of one degree of latitude. Marwarrūdhī designed instruments, including an armillary and an astrolabe, for observations made in Baghdad. Following the death of **Yaḥyā ibn Abī Manṣūr**, **ʿAbbās ibn Saʿīd al-Jawharī** selected Marwarrūdhī to prepare appropriate instruments for placement at the Dayr Murrān monastery on Mount Qāsiyūn near Damascus. There, he led the yearlong series of solar and lunar observations *circa* 832, though he encountered considerable difficulties with the warping and expansion of the copper and iron instruments. The first of three generations of astronomers, he also took part in the project circa 843/844 in Baghdad concerning observations for determining the length of the spring season.

Marvin Bolt

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Māshā'allāh ibn Atharī (Sāriya)

Died ***circa* 815**

Māshā'allāh (from mā shā' Allāh, *i. e.*, "that which God intends") was a Jewish astrologer from Basra. Ibn al-Nadīm says in his *Fihrist* that his name was Mīshā, meaning Yithro (Jethro). Māshā'allāh was one of the leading astrologers in 8th- and early 9th-century Baghdad under the caliphates from the time of al-Manṣūr to **Ma’mūn**, and together with al-Nawbakht worked on the horoscope for the foundation of Baghdad in 762.

Ibn al-Nadīm lists some 21 titles of works attributed to Māshā’allāh; these are mostly astrological, but some deal with astronomical topics and provide us information (directly or indirectly) about sources (*i. e.*, Persian, Syriac, and Greek) used during this period. This valuable information also comes from the Latin translations of some of Māshā’allāh’s works, some of which are no longer extant in Arabic.

A selection of the works by Māshā’allāh includes *De scientia motus orbis* (On Science of the Movement of Spheres), preserved in Latin translation, containing an introduction to astronomy as well as a study of **Aristotle**’s *Physics*, both based on Syriac sources. **Ptolemy** and **Theon of Alexandria** are mentioned, but the planetary models are pre-Ptolemaic Greek and similar to those found in 5th-century Sanskrit texts, *Kitāb fī al-qirānāt wa-’l-adyān wa-’l-milal* (A book on conjunctions, Religions, and communities), an astrological history of mankind, attempts to explain major changes based on conjunctions of Jupiter and Saturn; a discussion of eclipses is preserved in a Latin translation by John of Seville and a Hebrew translation by **Abraham ibn ʿEzra**, and a commentary on the armillary sphere. (For other works, see Sezgin.)

Misattributions have sometimes occurred because of confusion between the works of Māshā’allāh, **Abū Maʿshar,** and Sahl ibn Bishr. Indeed, the authenticity of two treatises on the astrolabe attributed to Māshā’allāh and translated into Latin has been questioned by P. Kunitzsch.

Finally, according to E. Kennedy, Māshā’allāh’s son was an astronomer who composed a manuscript unifying the theories of **Khwārizmī** and **Ḥabash**.

Ari Belenkiy

Alternate name

Messahala

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Messahala

Māshā’allāh ibn Atharī (Sāriya)

Maskelyne, Nevil

Born **London, England, 6 October 1732**
Died **Greenwich, England, 9 February 1811**

As Great Britain’s fifth Astronomer Royal and founder of the *Nautical Almanac*, Nevil Maskelyne made practical the finding of longitude at sea. Maskelyne was the third son of Edmund and Elizabeth Booth Maskelyne of Purton, Wiltshire, England. His father died when he was 11 years old. Maskelyne was educated at Westminster School and admitted to Trinity College, Cambridge University. He graduated seventh wrangler in mathematics in 1754, took Holy Orders in 1755, and became a fellow of his college. Maskelyne was elected a fellow of the Royal Society of London in 1758. He was appointed the fifth Astronomer Royal of England and director of the Royal Observatory at Greenwich in 1765; he held that office for 46 years. Maskelyne was also awarded his Doctor of Divinity (1777); he was named rector of Shrawardine, Shropshire (1775) and of North Runcton, Norfolk (1782). He married Sophia Rose in 1784; their only child, Margaret, was born the following year.

At the request of the Royal Society, Maskelyne traveled to the island of Saint Helena with Robert Waddington to observe the 6 June 1761 transit of Venus, but was defeated by clouds. On the same voyage, however, he was able to make longitude calculations using the so called "lunar distances" method advocated by Sir **Isaac Newton** and **Edmond Halley**, amongst others, and made possible by the improved lunar tables calculated by **Johann Mayer**. Maskelyne published the lunar distances method in *The British Mariner's Guide* (1763). While on Saint Helena, he carefully observed the tides, and the variation of the compass, and undertook measurements on the annual parallax of Sirius.

Finding longitude at sea was a major problem for sailors in the 18th century. Many ships had foundered as a result of not being able to determine their positions with accuracy. In 1714, the British Board of Longitude established a prize of £20,000 to facilitate the discovery of a reliable method for determining longitude at sea. It fell to Maskelyne (as Astronomer Royal) to examine the various solutions and inventions proffered to this problem. In 1763, he sailed to Barbados in order to test the reliability of John Harrison's fourth chronometer, H-4, and found its accuracy superior to the lunar distances method. Maskelyne also undertook longitude determinations by observing eclipses of Jupiter's Galilean satellites, and found this method was impractical on the deck of a ship at sea.

When Maskelyne succeeded **Nathaniel Bliss** as Astronomer Royal in 1765, he at last fulfilled the public function for which the Royal Observatory was founded by King Charles II in 1675, namely, the preparation of tables for ocean navigation. Maskelyne inaugurated publication of *The Nautical Almanac and Astronomical Ephemeris*, the first volume of which appeared in 1766 for the year 1767. It contained a compendium of astronomical tables and navigational aids, such as **James Bradley**'s tables of atmospheric refraction. Maskelyne had assisted Bradley in the preparation of such tables during the latter's tenure as the third Astronomer Royal in 1755. Maskelyne supervised publication of the *Nautical Almanac* for 50 years, from 1767 to 1816. He also published the cumulative Greenwich observations for the period from 1776 to 1811 in four volumes, containing positions of the Sun, Moon, planets, and selected reference stars. Maskelyne's work on the proper motions of several bright stars was used by Sir **William Herschel** to estimate the Sun's movement toward the constellation of Hercules.

In 1774, Maskelyne experimented with a plumb-line to determine the mean density of the Earth by measuring the gravitational deflection induced by a mountain. In the summer of the previous year, astronomer **Charles Mason** (of Mason–Dixon line fame) toured the highlands of Scotland and regions in the north of England in search of a suitable mountain. He eventually selected the peak of Schiehallion in the Cairngorm mountain range in Perthshire, Scotland. This mountain was reasonably isolated from other hills, had the desired east–west orientation (with a small north–south extent that Maskelyne sought), and had a relatively regular form to facilitate the calculation of its volume. In this experiment, Maskelyne investigated the principle and the constant of universal gravitation, confirming that the force of gravity acting between bodies is proportional to the inverse square of their separation. Charles Hutton analysed Maskelyne's data and calculated a value for the mean density of the Earth between 4.56 and 4.87 g cm^{-3}, as compared with the modern value of 5.52 g cm^{-3}. For this demonstration, Maskelyne received the Copley Medal of the Royal Society in 1775.

One of Maskelyne's correspondents was the Irish astronomer, James Archibald Hamilton, who operated a private observatory at Cookstown, County Tyrone. Hamilton communicated his observations of the 1782 transit of Mercury to Maskelyne, who commented favorably upon the results. Hamilton was later appointed the first astronomer of the Armagh Observatory in 1790. Maskelyne was requested to obtain precision clocks for the Armagh Observatory, and eventually recommended chronometer maker Thomas Earnshaw who subsequently produced two astronomical clocks for the Observatory. With Maskelyne's support, Earnshaw was awarded £3,000, under the new Longitude Act of 1774, for his innovative clock designs.

Maskelyne contributed to a number of fields of study, *e. g.*, he invented the prismatic micrometer, and edited Mason's improvements to Mayer's lunar tables. Yet, his most enduring legacy was his contributions toward the longitude problem and his establishment of the *Nautical Almanac*. Several lunar craters are named for him, Maskelyne W being the crater used as a finder by the crew of Apollo 11 during the lunar module's final descent onto the surface in 1969. The Maskelyne Islands in the Pacific Ocean are also named for our subject.

John McFarland

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Mason, Charles

Born	**Wherr, Gloucestershire, England, 1730**
Died	**Philadelphia, Pennsylvania, USA, 25 October 1786**

Charles Mason, a surveyor and astronomer, worked with **Jeremiah Dixon** on several astronomical expeditions including surveying the Mason–Dixon line delineating the boundary between Maryland and Pennsylvania. Although his father was a miller and a baker, Mason was educated at a private school, and became a professional surveyor. His first wife, Rebekah Peach, is believed to have been responsible for Mason's introduction to Astronomer Royal **James Bradley**, who appointed him assistant observer at the Greenwich Observatory in 1756; when Rebekah died in 1759 in Greenwich, on her tombstone was carved: "Wife of Charles Mason, Junr, ARS" (assistant of the Royal Society).

With the transit of Venus of 1761 impending, Bradley chose Mason to lead an observatory expedition to Bencoolen, Sumatra. On the voyage he was accompanied by Dixon, a surveyor and astronomer with a private observatory. They departed in November 1760 aboard *HMS Seahorse* with orders to proceed to Bencoolen unless it was in the hands of the French, in which case they would divert to Batavia. While still in the English Channel the *Seahorse* was attacked by the French frigate *Le Grand.* After a violent battle, which lasted barely an hour, the captain was able to return the ship back to Plymouth. However, upon witnessing the casualties and damage to both the ship and some of the astronomical equipment, Mason and Dixon wrote of their desire of not going to Bencoolen. Instead, Mason suggested the eastern portion of the Black Sea, from where they would be able to observe first contact, but not the planet leaving the face of the Sun.

The Royal Society not only denied their request but threatened them with a law suit, so the voyage to Bencoolen was recommenced. However, by the time they were rounding the Cape of Good Hope, they received news that Bencoolen had been taken by the French. Arriving at the Cape of Good Hope in April 1761, Mason and Dixon prepared to observe the transit from there. As luck would have it, their observations at the Cape of Good Hope were the only successful ones for the South Atlantic region; everywhere else was clouded out.

Afterward, Mason and Dixon joined **Nevil Maskelyne** on the island of Saint Helena, assisting him in various measurements, such as for tides, longitude, and the gravitational constant.

In 1763, as a result of the successful collaboration with respect to the transit of Venus, Mason and Dixon were charged with the responsibility of surveying what is still referred to as the Mason–Dixon line. The language of the original land grants to William Penn (later Pennsylvania) and to Lord Baltimore (later Maryland) was sufficiently vague that, by the mid-18th century, the argument between their respective heirs required the appointment of a commission in 1760 to adjudicate the border dispute. Three years later, Mason and Dixon were hired to survey and establish the boundary. Arriving in America in November 1763, they set up their equipment: two transits, two reflecting telescopes, and a zenith sector. Within a month, the two had measured the southernmost latitude of Philadelphia: 39° 56′ 29.1″ N and began the survey proper.

During the first few months, Mason and Dixon followed the old "temporary line" surveyed in 1739 by Benjamin Eastburn. This brought them through small townships such as Darby, Providence, Thornbury, West Town, and West Bradford. From there they continued to travel westward, as they were directed, to continue along the parallel of latitude as far as the country was inhabited. The surveyors continued until September of 1767 where, at Dunkard Creek, their Indian guide informed them it was the will of the Six Nations that the survey be stopped. They returned to England a year later in September 1768.

Because of their experience and their quality observations in 1761, Mason and Dixon were again asked to participate in an expedition for the 1769 Venus transit. Mason did not wish to participate; at the last minute, he grudgingly agreed to travel to County Donegal in Ireland. Only Dixon was willing, and he observed from the island of Hammerfest, off the Norwegian coast.

After the transit, Mason returned to England and continued his professional association with Maskelyne and the Royal Society. He was charged with aiding in the solution to a problem Sir **Isaac Newton** had devised decades earlier: Whether large land masses, such as mountains, could draw a plumb line up to 2 min out of the true perpendicular. Maskelyne had been intrigued with this problem for many years, and upon receiving funding to test it, in 1773 he commissioned Mason to select a suitable hill. Traveling to Scotland, Mason chose Schehallien, in Perthshire. And then, quite suddenly, Mason returned to England, quitting what some believe could have been his greatest scientific feat. Apparently, he had remarried, and desired to remain in England, where he worked on the *Nautical Almanac*, cataloging fixed stars and determining precise positions for the Moon.

Unfortunately, Mason's health was failing; apparently, his years in America had left him in a weakened state. Also, his second marriage added six children to his original two, and he was feeling the strain of poverty. For reasons unknown, Mason and his entire family sailed to Philadelphia, where he died shortly after arrival and was buried in Christ Church Burying Ground, in an unmarked grave.

Francine Jackson

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Mästlin [Möstlin], Michael

Born **Göppingen, (Baden-Württemberg, Germany), 30 September 1550**
Died **Tübingen, (Baden-Württemberg, Germany), 20/30 October 1631**

Michael Mästlin was a noted observer and mathematician himself, but is perhaps best known as the teacher of **Johannes Kepler**.

Mästlin was the son of Jakob Mästlin and Dorothea Simon (died: 1565), who were pious Lutherans; he had a younger brother and an older sister. Young Michael was sent to the monastic school in Königsbronn, and eventually he enrolled at Tübingen University in 1568. There, Mästlin studied mathematics and astronomy under Philip Apian (the son of the famous astronomer **Peter Apian**), whom Mästlin eventually replaced. Mästlin received his master's degree, *summa cum laude*, from Tübingen University in 1571. He tutored and taught there until he was called to be a deacon at the Lutheran Church in Backnang in 1576. There, Mästlin married Margarete Grüninger (1551–1588) in April 1577, who bore him three sons and three daughters; she died (possibly due to childbirth complications), with their sixth child. Mästlin then married Margarete Burkhardt, a daughter of a Tübingen professor, in 1589; they had eight more children.

Mästlin's publication of his careful observations of the comet of 1577 brought him fame as an astronomer. His reputation rose across Europe, leading to his appointment as a professor of mathematics at the University of Heidelberg in 1580. In 1584 Mästlin returned to the faculty at Tübingen, where he remained until his death.

For a while in the late 1570s, Mästlin was apparently the chief scientific advisor to his patron, Duke Ludwig III of Württemberg. Ludwig's successor, Duke Friedrich I, also relied on advice and opinions from Mästlin. At Tübingen, Mästlin was elected dean of the arts faculty several times. He was well liked by both his colleagues and his students. Mästlin was very generous both to his family and to others. He was a religious man; he followed the Lutheran line in opposing the Gregorian calendar reform partly because it was initiated by the pope. Mästlin had several students who became noted mathematicians, the most famous being Kepler. Mästlin also maintained interests in Biblical chronology and geography.

Mästlin was a prolific scholar of astronomy, writing extensively and corresponding with other astronomers throughout Europe. He can be considered the first astronomer to offer an orbit of a comet (though he did not use a proper procedure), putting the comet of 1577 in a heliocentric orbit just outside the orbit of Venus; he claimed that this supported the Copernican model of heliocentrism. Mästlin was an eager mathematician, working with spherical trigonometry to convert his observations to a useful format, and followed the published works of **Johann Müller** (Regiomontanus), Region Ontarus, Peter Apian, and **Caspar Peucer** in doing this. Mästlin read scholarly books very carefully, making extensive notes in many of his own books in a neat, small handwriting. For example, he heavily annotated his personal copies of **Nicolaus Copernicus'** *De revolutionibus* (noting, among many other things, numerous typographical errors in cataloged star positions), **Tycho Brahe's** *De mundi aetherei* on the 1577 comet (carefully assessing the positional observations), and **Johann Schöner's** 1544 treatise containing observations of Müller and **Bernard Walther** (where Mästlin seemed quite interested in eclipse measurements).

Through Mästlin's course on astronomy used his own textbook that followed Ptolemaic themes, this was likely due to the fact that basic astronomy (as taught at a low level at that time) did not need the technical aspects of Copernicus's heliocentrism and Müller's spherical trigonometry. In more advanced courses, these more technical aspects were evidently taught by Mästlin, who was widely known as a heliocentrist. That reputation had its origin in Mästlin's tract on the 1577 comet in which he placed the comet in a Venus-like orbit about the Sun, as did Brahe in his grand book on the same comet a decade later. Both Mästlin and Brahe credited the idea for such an orbit to **Abū Maʿshar**. Kepler credited Mästlin with having introduced him to Copernicus' philosophy during Kepler's student years at Tübingen (1589–1594). Kepler's mentor wrote an appendix entailing discussion of Copernican astronomy in the younger astronomer's first major publication, *Mysterium Cosmographicum* (1596, Tübingen). Mästlin maintained a long, productive correspondence with Kepler on astronomical matters. Kepler probably owed much of his own development of astronomical thought over the years to the training that he received from Mästlin.

In the late 1570s, Mästlin prepared for publication his *Ephemerides novae*, which were ephemerides of the planets based on Copernican theory (following the work of **Erasmus Reinhold**). Mästlin duly noted that the ephemerides needed correcting because the observations upon which they were based lacked accuracy, and he stated that Copernicus' theory is truer than older ideas. Following Regiomontanus, Peter Apian, and others from the previous 100 years, Mästlin joined his own generation of observers (including Brahe) in working carefully to obtain the best positional measurements possible of celestial objects and thereby improve the state of knowledge in astronomy.

Mästlin was known in his lifetime as a first-rate astronomical observer —his good eyesight is indicated by his drawing in 1579 of 11 stars in the Pleiades— and as an astronomer who was willing to challenge intelligently the old way of thinking about astronomy through the use of observations obtained in a more detailed and systematic fashion. In his early years, Mästlin improvised by using a thread to determine the position of transient objects (1572 supernova; comet of 1577) by checking their alignments with various stars. He impressed Brahe by finding that the supernova (B Cas) showed no parallax and must therefore be as distant as the other stars, attacking the Aristotelian position that the stellar region is unchanging. By 1577 Mästlin was using a clock to record times of observation; his was the first generation of astronomers where timekeeping was taken to be important, and times were noted often, despite the poor quality of timepieces then. Mästlin's tracts on comets and the 1572 supernova notably parallel Brahe's own tracts on these objects in that, unlike other typical treatises on such objects in that era, they concentrated on observations and reductions of observations while keeping astrological speculation to a bare minimum. Mästlin is also credited with being the first to publish his own finding that the unlit part of the crescent Moon glows faintly due to sunlight reflected off the Earth onto the Moon.

Though he was unable to undertake a huge observational program, such as Brahe did at Hven, Mästlin was an important influence on Brahe's work through his correspondence. Mästlin challenged his contemporaries to improve observational data rather than to just accept what had been passed down from the ancients through medieval times. He was also familiar with constructing sundials, celestial globes, quadrants, cross-staffs, and maps – all knowledge that was likely passed on to a large degree from his professor Philip Apian at Tübingen. Within 4 years of **Galileo Galilei**'s first pointing a telescope skyward, Mästlin had obtained two small telescopes which, though rather poor, showed him sunspots and the satellites of Jupiter. Mästlin remained an eager astronomical observer into his late years, making notes of his observations of the comets of 1618 and of a lunar eclipse in 1628.

Much of Mästlin's library now resides at the Municipal Library in Schaffhausen, Switzerland.

Daniel W. E. Green

Alternate names

Moestlinus
Möschlin, Michael

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Mathurānātha Śarman

Flourished **Bengal, (India), 1609**

Mathurānātha Śarman composed the *Ravisiddhāntamañjarī* or *Sūryasiddhāntamañjarī*, an astronomical treatise consisting of four chapters and tables, in 1609. This work uses parameters belonging to the *Saurapakṣa*, one of the traditional schools of astronomy in India. The tables are for calculating the longitudes of the planets; there are also parallax tables for computing solar eclipses. He may have composed two other works, the *Pañcaṅgaratna* and the *Praśnaratnāṅkura* or *Samayāmṛta*.

Setsuro Ikeyama

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Maudith, John

Flourished **1309–1343**

John Maudith produced astronomical tables in the early 14th century. In 1310 he compiled tables for the rising and setting times of stars. Maudith's tables were essentially Toledan tables recomputed for the Oxford meridian. He drafted a separate catalog of bright stars, epoch 1316, with stellar positions calculated according to **Thebit ibn Qurra's** theory of trepidation.

Very little is known of Maudith's life. Between 1309 and 1319 he was a fellow of Merton College, Oxford. The Merton *Catalogus vetus* describes him as a good astronomer and physician. After leaving Oxford, Maudith joined Richard de Bury's scholarly circle at Durham; **Thomas Bradwardine** was one of his colleagues there. Maudith later served John de Warenne, Earl of Surrey and Sussex, probably as a physician. He wrote a *Tractatus de doctrina theologica* dated to 1343.

Keith Snedegar

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Maunder, Annie Scott Dill Russell

Born **Strabane, Co. Tyrone, (Northern Ireland), 14 April 1868**
Died **London, England, 15 September 1947**

Solar astronomer Annie Russell joined her husband, **Edward Walter Maunder**, in supporting amateur astronomers in Britain by editing their journal and leading solar eclipse expeditions, while continuing her own solar research and popular writing on astronomy.

Russell was the first daughter of the Reverend William Andrew Russell, a minister of the Irish Presbyterian Church, and his second wife, Hester (*née* Dill). Annie had two half-brothers from her father's first marriage and two brothers and one sister from the second. For her secondary education, she attended the Ladies' Collegiate School, Belfast (renamed Victoria College in 1887), known as the premier institution for the education of girls in Ireland. Russell decided not to work for an Irish university degree but, instead, took the Girton College open entrance examination. By studying diligently, she overcame a deficit in her early training and upon graduation won the highest mathematical honor available to a woman, Senior Optime in the mathematical *tripos*. (When Russell graduated, women were allowed to sit for the Cambridge *tripos* examinations, although they were not granted a university degree.)

Upon leaving Girton College, Russell became a mathematics teacher at the Ladies' College, Jersey, but found teaching unrewarding. After learning of a possible vacancy for a "lady computer" at the Royal Greenwich Observatory, she applied for the position, even though the pay was much less than she earned as a teacher. She accepted the post and, while measuring daily sunspot photographs, met Maunder, head of the solar photography department. In 1890, Maunder had assisted a number of leading amateur astronomers in founding the British Astronomical Association [BAA] after the collapse of the Liverpool Astronomical Society. Together, Russell and Maunder worked on the association's journal. She was its first editor, from 1894 to 1896, and served an additional term, from 1917 to 1930.

In 1895, Russell married Maunder, and they worked together on numerous astronomical projects. Annie, however, was obliged to resign her position as Walter's paid assistant at Greenwich. Walter and Annie had no children of their own, but 45-year-old Walter was a widower with five children when he married the 27-year-old Annie. Although she continued with her astronomy, much time was spent in rearing her stepchildren. In another sense, her marriage to Walter proved fortunate for Annie Maunder's career. Through her husband, she was able to borrow instruments, establish contacts with other astronomers, and travel to various eclipse sites. Probably the most important factor was Walter's view that women deserved an important place in astronomy.

Maunder made many contributions to astronomy. Shortly after her marriage, she received the Pfeiffer Research Student Fellowship, established to upgrade the Girton College research potential. As the first recipient of this fellowship (1896), she used the money to undertake a photographic study of the Milky Way. At Greenwich, she was assigned to the solar department as a photographic assistant. Maunder's work involved photographing the Sun and examining the negatives with a micrometer. Recruited during the approach of a sunspot maximum, she noted the positions of the sunspots and worked on interpreting the phenomena.

Although much of her astronomical work was done in collaboration with Walter, Annie was an important contributor to astronomy in her own right. She published numerous papers and a book, *The Heavens and Their Story* (1908). Although Walter's name appeared as coauthor, he insisted that Annie had done all of the writing. Her professional level of competence was gained from formal university training, working as a paid assistant, and from informal training by her husband.

Maunder's prodigious output included theoretical work. She developed a theory that the Earth influences the numbers and areas of sunspots, and that sunspot frequency decreases from the eastern to the western edge of the Sun's disk (as viewed from Earth). With Walter and the BAA, she went on solar eclipse expeditions and became an expert eclipse observer. One of her photographs revealed a coronal streamer extending out to six solar radii – the longest then observed to that date. Maunder published numerous reports on these eclipses, and many papers on the history of astronomy, especially early accounts of the constellations.

Gender must be considered when examining Maunder's career. While she possessed all of the requisites to be a professional scientist, as a woman, she received less than full recognition of her qualifications and contributions from male professional astronomers. Fortunately, her husband recognized the importance of women to astronomy. Through a variety of channels including the BAA, she and other women astronomers were able to make their contributions.

Maunder's papers may be found in the Archives of the British Astronomical Association, the Archives of the Royal Astronomical Society, and the Archives of the Royal Greenwich Observatory.

Marilyn Bailey Ogilvie

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Maunder, Edward Walter

Born **London, England, 12 April 1851**
Died **London, England, 21 March 1928**

Walter Maunder is chiefly remembered for his work in the field of solar studies. His plot of the latitude drift of sunspots is known as the Maunder butterfly diagram. The lapse in sunspot numbers during the interval from 1645 to 1715, which he investigated, has been termed the Maunder minimum.

The youngest of three sons of the Reverend George Maunder, a Wesleyan minister, Maunder's basic education was acquired at the school attached to University College in Gower Street, London, and supplemented with additional courses at King's College, London. He worked briefly in a City of London bank before taking the first-ever examination set by the British Civil Service Commissioners (1872), designed to fill vacancies created at the Royal Greenwich Observatory. With his appointment as photographic and spectroscopic assistant in 1873, the observatory entered the realm of astrophysics, or the New Astronomy, as it was called by **Samuel Langley**.

Maunder spent 40 years at Greenwich and became superintendent of the solar department, working chiefly under the direction of **William Christie**. Starting in 1874, Maunder operated the photoheliograph, taking daily photographs of the Sun (originally on wet plates, later on dry), then measuring and tabulating the numbers, areas, positions, and motions of sunspots. Data acquired over the next 30 years enabled Maunder to affirm what was known about the axis of solar rotation, the equatorial drift and periodicity of sunspots, and the Sun's differential rotation from the work of **Samuel Schwabe** and **Richard Carrington**. Another important finding was the observed correlation between solar activity and terrestrial magnetic disturbances, a subject discussed in a series of papers starting in 1904.

In 1887 and 1889, **Gustav Spörer** drew attention to a long continued absence of sunspot activity, from about 1645 to 1715. Maunder summarized Spörer's papers for the Royal Astronomical Society in 1890, and began his own search of historical records. Maunder published an article, entitled "A Prolonged Sunspot Minimum," which supported Spörer's conclusions. It attracted little attention. Nor did an article with a similar title, published in 1922. Only in the mid-1970s, after solar physicist John A. Eddy took a fresh look at the evidence, were Maunder's findings confirmed. This anomaly was named the Maunder minimum. Spörer's name is given to an earlier, similar epoch.

Maunder also undertook observations of solar prominences, the spectra of comets, planets, novae, and nebulae, and was a keen follower of total solar eclipses, observing those of 1886 (Carriacou, West Indies), 1896 (Vadsö, Norway), 1898 (India), 1900 (Algeria), 1901 (Mauritius), and 1905 (Canada). He was elected a fellow of the Royal Astronomical Society in 1875, served as a council member for several years, and was its secretary (1892–1897).

In 1890, Maunder and his brother, Thomas, played a central role in the formation of the British Astronomical Association [BAA], whose purpose was "to afford a means of direction and organization in the work of observation to amateur astronomers." He served as its third president (1894–1896), and was acting secretary (1914–1915). Maunder headed the Mars Section (1892–1893), the Star Colour Section (1900–1902), and the Solar Section (1910–1925). He likewise edited the association's *Journal* for a number of years, having previously edited *The Observatory* (1881–1887).

In all of these investigations, Maunder received invaluable help from his second wife, Annie, who was academically more qualified than her husband. **Annie Maunder** graduated from Girton College, Cambridge, as senior optime in the mathematical *tripos*, and joined the Royal Greenwich Observatory staff as "lady computer" in 1891. She and Walter were married in 1895 and worked closely together on the solar data, although Annie was obliged to resign her post as Maunder's paid assistant. Together, they provided leadership to a series of successful solar eclipse expeditions sponsored by the BAA.

Maunder retired from Greenwich at the end of 1913, but was recalled to maintain the sunspot record during World War I. Between 1914 and 1916, he served as secretary of the Victoria Institute, London, a society founded in 1865 to investigate questions of philosophy and science, especially those bearing upon religion.

Maunder and his wife published several books, including a history of the Royal Greenwich Observatory (1900), and many articles and papers in the *Monthly Notices of the Royal Astronomical Society*, and the *Journal of the British Astronomical Association*. They were frequent contributors to *Knowledge* and *Nature*.

Richard Baum

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Maupertuis, Pierre-Louis Moreau de

Born **Saint-Malo, (Ille-et-Vilaine), France, 28 September 1698**
Died **Basle, Switzerland, 27 July 1759**

In astronomy, Pierre de Maupertuis contributed to the understanding and diffusion of **Isaac Newton**'s theory in France and in continental Europe. He arranged for, and participated in, measurements to ascertain the shape of the Earth. In physics, Maupertuis was the first to formulate the least-action principle. He also made contributions to mathematics, biology, heredity, and moral philosophy. As a prolific intellectual, Maupertuis opened new roads in science.

Maupertuis' father, René Moreau, was a layperson. Maupertuis was raised by his overcautious mother and first educated at home. For philosophical instruction, he attended the Collège de la Marche in Paris in 1714. At his mother's request, he returned to Saint-Malo in 1716 and gave up his wish to go to sea. After a visit to Holland in 1717, Maupertuis moved back to Paris where he began musical studies, but switched to mathematics.

In 1718, Maupertuis joined the *Mousquetaires Gris* and in 1720, with the rank of lieutenant, was stationed in Lille. During his army period, he devoted all his free time to geometry. In the following year, he resigned his commission and returned to Paris. There Maupertuis joined a group of scholars, three of whom were members of the Académie royale des sciences, through whose intervention he was elected to the academy on 14 December 1723 as an *adjoint-géomètre*, the lowest position, despite having no publications.

In August 1725, a short time after the publication of his first paper devoted to the influence of shape on the properties of musical instruments, Maupertuis was promoted to *associé*. From 1723 to 1733, he published various memoirs concerning geometry, mathematics, and zoology; the memoir *Sur la question des maximis et des minimis* was the first step in his formulation of the least-action principle.

Maupertuis made his first foreign journeys, to London in 1728, to Basle – he registered there as a student – in 1729, and again to Basle the next year. These journeys played a major part in his future intellectual evolution. In London, Maupertuis was in the center of the Newtonianism, of observational science, and of watch and instrument making. He was admitted to the Royal Society on 27 June 1729 (O.S.). In Basle Maupertuis met **Johann Bernoulli**, from whom he received an excellent general scientific training and an introduction to **Gottfried Leibniz**' thought. Throughout his life, Maupertuis found friendship and support from the Bernoulli family.

During the 1730s, Maupertuis published many papers. 1731 was the year of both the publication, in England, of the *De Figuris*, his first astronomical paper, and his election as a *pensionnaire-géomètre* to the academy. The publication, in the following year, of his *Discours sur la figure des astres* is considered to be the first book promoting widely the Newtonian theory in France and continental Europe. While he presented Cartesianism and Newtonianism with some symmetry, Maupertuis did in fact support the latter.

The question of the exact shape of the Earth was of central importance, particularly to the academy, because **Jacques Cassini**'s and colleagues' measurements led to a prolate model of Earth, whereas Newtonians argued for an oblate Earth. During the period 1732–1735, Maupertuis studied the consequences of the law of attraction on the Earth's shape and other celestial bodies. Because of dissension, the academy ordered two expeditions to measure the length of a degree along a meridian at two very different latitudes. **Charles de la Condamine**, **Louis Godin**, and **Pierre Bouguer** led an expedition to Peru, while Maupertuis and **Alexis-Claude Clairaut**, who already worked together, led a second one to the Gulf of Bothnia. Before sailing to Lapland, both were trained in observing and measuring by Jacques Cassini. The abbé **Réginald Outhier,** a member of the Academy of Caen and an astronomer, accompanied them and chronicled the expedition in his *Journal d'un voyage au Nord, en 1736 & 1737*. This expedition may have been one wherein **John Hadley**'s octant was first used. Whereas the expedition to Peru lasted about 10 years, the Lapland team returned to Paris on 20 August 1737, just 16 months after departure. Their measurements confirmed the oblateness of Earth.

Maupertuis made two reports to the academy (1737 and 1738) but came under attack. He carried on his argument with Cassini in his *Examen désintéréssé des différents ouvrages qui ont été faits pour déterminer la figure de la Terre*, published in 1738 or 1739. Waiting for the return of the Peru mission, the Lapland astronomers reassembled in August 1739 and made a new measurement of the arc between Amiens and Paris, measured by **Jean Picard** in 1669. To support his position on the Earth's figure, Maupertuis published three works in 1740: *Éléments de géographie*, *Degré du méridien entre Amiens et Paris*, and *Lettre d'un horloger anglois à un astronome de Pékin*, this last an ironic literary piece attacking Cassini's followers in the academy. During this period, Maupertuis carried on a wide correspondence with leading European scholars. He also taught Mme du Chatelet geometry and calculus.

Maupertuis had been elected an *associé-étranger* of the Berlin Academy in 1735 and was so informed when he returned from Lapland. When Frederick II became King of Prussia in 1740, he wished to reform his academy and invited Maupertuis to come to Berlin. In September 1740, Maupertuis arrived there for the first time. Going to meet Frederick at Mollwitz, during the War of Austrian succession in the following year, Maupertuis was taken prisoner by the Austrians, but was well received by the court in Vienna. In 1745, he settled in Berlin and, in August, married Eleonor de Bork, a noblewoman he had met on an earlier visit. Maupertuis assumed the presidency of the Berlin Academy on 3 March 1746. Although he had been active in the Paris Academy (*sous-directeur* in 1735 and 1741, directeur in 1736 and 1742), he now had to resign. He was also a member of the Académie française.

In Paris, before his official installation in Berlin, Maupertuis penned his *Discours sur la parallaxe de la Lune pour perfectionner la théorie de la Lune et celle de la Terre* (1741), *Lettre sur la comète* (1742), and *Astronomie nautique* (1743). All dealt with Newtonian solutions to various questions.

In the later 1740s and 1750s, Maupertuis turned more to speculative and natural philosophy and to his routine work for the Berlin Academy. He published many of his ideas in letters. As president, he supported astronomical work, including the first precise measurement of lunar parallax thanks to observations by **Joseph-Jérome de Lalande** (another Berlin academician) at Berlin and by **Nicolas de La Caille** at the Cape of Good Hope.

Maupertuis was the first to formulate the least-action principle, which he considered as the summit of his work. He published on statics in *Loi du repos des Corps* in 1740; he applied the ideas to optics in a paper "*Accord de différentes lois de la Nature qui avoient paru incompatibles*" (1744). To extend the ideas to mechanics, Maupertuis assumed collisions of massive points. His full ideas appeared in *Essay de Cosmologie* in 1750.

Samuel König, a Berlin academician and long-time friend, claimed that Leibniz had indicated, in a letter, that he had been the first to formulate the principle. Although in poor health, Maupertuis fought to maintain his priority, and the fight drew in many from Berlin intellectual circles. As the Leibniz letter could not be found, the academy supported Maupertuis in a meeting of 13 April 1752, forcing König to resign. This resulted in much hostility towards Maupertuis, including a virulent attack by Voltaire, in his *Diatribe du docteur Akakia* (1752), which portrayed him as an arrogant fool.

In his last years Maupertuis produced works on reproduction, heredity, and pleasure, including *Dissertation physique à l'occasion du nègre blanc* (1744) and *Vénus physique* (1745). In the *Système de la nature* of 1751, Maupertuis speculated on parental heredity, anticipating some ideas of the following century. He left Berlin for the last time in June 1756. He was reinstalled in the Paris Academy on 15 June. A final journey in 1759 took him to Bernoulli's home in Basle, where Maupertuis died. At Saint-Roch in Paris, a marble funeral stele was erected by his friends in 1766.

Monique Gros

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Maurolico, Francesco

Born **Messina, (Italy), 16 September 1494**
Died **near Messina, (Italy), 21 or 22 July 1575**

Francesco Maurolico, in addition to doing original work, translated and commented on works by ancient authors such as Euclid, **Apollonius**, and **Archimedes**.

Maurolico spent nearly all of his life in Sicily, where he was ordained a priest in 1521, and held various ecclesiastical as well as civil posts. His astronomical writings include a criticism of **Nicolaus Copernicus**, and a treatise on the use of the principal astronomical instruments. Maurolico's observation of the supernova of 1572 in Cassiopeia (SN B Cas) appears to predate that of **Tycho Brahe** by five days.

Katherine Bracher

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Maury, Antonia Caetana de Paiva Pereira

Born **Cold Springs, New York, USA, 21 March 1866**
Died **Hastings-on-Hudson, New York, USA, 8 January 1952**

American spectroscopist Antonia Maury discovered a way of recognizing supergiant stars from their spectra, even when their distances could not be measured. She was the granddaughter of **John William Draper**, the first person to photograph the Moon, the niece of **Henry Draper**, another keen amateur astronomer, and the daughter of Mytton and Virginia (*née* Draper) Maury. Her father, an Episcopalian priest, edited volumes in natural history; a sister became a paleontologist and a cousin an oceanographer. Maury was taught largely by her father and uncle, going on to Vassar College, New York, where she was one of the last students of **Maria Mitchell**, and received a BA in 1887.

In 1888, Maury was employed by **Edward Pickering** at Harvard College Observatory as part of a program to determine the spectral types of stars. The program was funded by a memorial contribution from Henry Draper's wife in his honor, and eventually published as the Henry Draper Catalog. **Williamina Fleming** and **Annie Cannon** were also employed in this project. Maury was probably the most intellectually gifted of the three women. Although she had been employed to classify objective-prism spectra into the system defined by Pickering and Fleming, she instead set up her own system. It improved on the earlier system in two ways. First was a finer gradation by the temperatures of stars; Maury was the first to recognize that the temperature sequence should be O, B, A. Second, she noticed that in some cases the spectral features were unusually hazy (her type b) and in some cases unusually sharp (her type c). These and other details that Maury recorded were regarded by Pickering as a waste of time, and it was not until about 1907 that **Ejnar Hertzsprung**, who had independently discovered supergiants by another method, recognized the importance of Maury's class c. Her own catalog, with the a, b, and c characteristics and a variety of additional kinds of information including notes on composite spectra and emission lines, appeared in the *Harvard College Annals* in 1897. Many of Maury's "b" types were later recognized as rapid rotators, an interpretation she had herself suggested.

Maury was also a pioneer in the investigation of spectroscopic binaries. Pickering had discovered the first of these, Mizar, from the doubling of its calcium K line in 1889. Maury found the second, β Aurigae, the same year and was the first to measure the orbital periods of both. She was no longer formally employed by Harvard College Observatory after 1892 but continued to analyze spectra taken there until 1935, including a large number of plates of the very peculiar eclipsing binary β Lyrae. This work appeared periodically in the *Harvard Annals Bulletin* until 1935.

Maury lectured in several east-coast colleges and served for several years as curator of Draper Park Museum. She was also a recognized ornithologist and naturalist.

Maury was, somewhat ironically, the 1943 recipient of the Annie J. Cannon Prize of the American Astronomical Society, the only major recognition she ever received. Her relationship with Harvard College Observatory, though informal, became much smoother under the directorship of **Harlow Shapley**.

Virginia Trimble

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Maury, Matthew Fontaine

Born **near Fredericksburg, Virginia, USA, 14 January 1806**
Died **Lexington, Virginia, USA, 1 February 1873**

A naval officer best known for his wind and current charts and therefore considered one of the founders of oceanography, Mathew Maury was, in effect, the first superintendent of the Depot of Charts and Instruments, though **James Gillis** might more properly be considered its founder.

Maury became a midshipman in 1825 and had three periods of sea duty through 1834. Two years later he authored a widely used textbook, *A New Theoretical and Practical Treatise on Navigation*. Promoted to lieutenant in 1836, Maury suffered a leg injury in 1839 that confined him permanently to shore duty, a situation that would greatly affect the remainder of his naval career. In 1842 Maury was named officer-in-charge of the Depot of Charts and Instruments, founded in 1830 to centralize the Navy's navigational maps and technology. Maury became the first superintendent of a newly equipped depot established by Congress with a "small observatory" in 1844. That depot quickly grew into the United States Naval Observatory and Hydrographic Office, an agency Maury headed until he joined the Southern cause in the Civil War in 1861. Maury was promoted to the rank of commander in 1858, retroactive to 1853.

During his years as the superintendent, Maury struggled to balance astronomy and hydrography. His main achievements were in the latter; the wind and current charts, based upon data that sea captains submitted to the depot, greatly shortened ocean voyages. In astronomy Maury oversaw observations made with a variety of astrometric instruments, and produced widely praised star catalogs. He struggled with limited resources, but his undoubted achievement is that he turned a small depot into the first national observatory of the United States, on a par with the Greenwich Observatory in England and other national observatories around the world. Maury was often considered an outsider among the new breed of professional American scientists, and his legacy in the scientific establishment was complicated by strong feelings stemming from his role in the Civil War.

Steven J. Dick

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Maxwell, James Clerk

Born **Edinburgh, Scotland, 13 June 1831**
Died **Cambridge, England, 5 November 1879**

It was while competing for the fourth Adams Prize that James Maxwell wrote a paper on Saturn's rings, in which he proposed that they were made of small particles, and could not be solid.

Maxwell's father was John Clerk; Maxwell was added later for inheritance purposes. His mother was Frances Cay. Maxwell was brought up in the Scottish countryside on an estate at Middlebie, Galloway, in a house called Glenlair. His mother died when he was 8 years old, and after an unsuccessful spell with a private tutor, he was educated at Edinburgh Academy, from 1841. Maxwell wrote a paper on the geometry of ovals when he was 14.

Maxwell went to Edinburgh University in 1847, then to Peterhouse College, Cambridge, in 1850, transferring to Trinity College and graduating in 1854. In 1856 he took up the post of professor of natural philosophy at Marischal College, Aberdeen, to be close to his father who was ill.

Maxwell married Katherine Mary Dewar, the daughter of the principal of Marischal College, but this did not prevent him from losing his position when Marischal College and King's College in Aberdeen were merged in 1860. In 1861 he was elected a fellow of the Royal Society.

Maxwell was turned down for a chair at Edinburgh University, and was appointed chair of natural philosophy at King's College, London until 1865. He then divided his time between Glenlair and Cambridge, where he designed the Cavendish Laboratory, which opened on 16 June 1874.

In 1866, Maxwell formulated, independently of Ludwig Boltzmann, what is now known as the Maxwell–Boltzmann kinetic theory of gases. Later, Maxwell developed the famous equations describing electromagnetism that bear his name.

David Jefferies

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Mayall, Margaret Walton

Born **Iron Hill, Maryland, USA, 27 January 1902**
Died **Cambridge, Massachusetts, USA, 6 December 1995**

Over a period of 24 years, Margaret Walton Mayall led the American Association of Variable Star Observers [AAVSO] to a position of international leadership among variable star organizations while providing substantial support to professional variable star astronomers and for amateur and popular astronomy through her publications. Mayall studied at the University of Delaware, Swarthmore College (BA: 1924), and Radcliffe College Harward University, where she earned an MA in Astronomy in 1927. With the help of **Leslie Comrie** at Swarthmore, Mayall found employment at Harvard College Observatory [HCO]. From 1924 to 1954 she worked at HCO as a research assistant, and later as Pickering Memorial Astronomer. She spent the summers of 1925 and 1926 as first assistant to Margaret Harwood, director of the Maria Mitchell Observatory in Nantucket, Massachusetts, and it was there that she first became interested in variable stars. It was also Nantucket where she met Robert Newton Mayall. They were married in 1927, but had no children. During World War II and for a year beyond (1943–1946), Mayall served in the research staff of the Heat Research Laboratory, Special Weapons Group, Massachusetts Institute of Technology.

While at HCO, Mayall assisted **Annie Cannon** in the classification of the spectra of faint stars and the estimation of the brightness of catalogued stars. She worked with Cannon until the latter's death in 1941, and then completed Cannon's unfinished spectral work, editing the results for publication as the second volume of *The Henry Draper Extension—The Annie J. Cannon Memorial* in 1949. Mayall published many other technical monographs while working at HCO.

Early in 1949, HCO Director **Harlow Shapley** asked Mayall to consider taking over the position of AAVSO recorder from **Leon Campbell** when he retired. The AAVSO was founded in 1911 by **William Olcott** in response to HCO director **Edward Pickering**'s efforts to collect observations of variable stars. From about 1918 to 1954, the AAVSO was headquartered at and run under the auspices of HCO. In 1949, Mayall accepted the position and was named Pickering Memorial Astronomer at HCO and AAVSO recorder. (The title was later changed to director.) She remained director of the AAVSO for 24 years until her retirement in 1973.

When Shapley retired from the HCO directorship in 1952, AAVSO's position began to change. With an inadequate budget, aging telescopes and other facilities, and aspirations for a rather different type of organization, the new HCO director, **Donald Menzel**, was forced to reconsider observatory priorities. In 1954, he announced that the AAVSO would have to move out of the observatory, and the endowment that supported the Pickering Memorial Professorship would no longer be available. With a new title of director, Mayall oversaw the transition of the AAVSO to an independent, nonprofit scientific and educational organization. As the association struggled through severe financial hardship Mayall worked without salary for a number of years to ensure the future of the AAVSO.

Through her determination, persistence, and vision, and with substantial help from **Clinton Ford** and other AAVSO leaders, Mayall secured the future of the AAVSO in many important ways. During the critical early years of independence, she actively sought out new sources of funding from government, industry, and private donors. She communicated widely with the astronomical community to solicit both technical and moral support for the AAVSO from the professional community; she established an endowment fund to secure a firmer financial footing for the AAVSO; she expanded existing programs and committees and added new ones to attract a broader membership; she added more stars to the observing program and established new systems for correlating and publishing data for professional use; and in 1967 she introduced modern data processing methods at the AAVSO, with emphasis on machine computing and plotting for publication. Mayall retired as director emeritus of the AAVSO in 1973.

As a member of the International Astronomical Union [IAU], Mayall participated in the activities of two IAU commissions, Commission 27 on Variable Stars, and Commission 29 on Stellar Spectra. She was a fellow of the American Association for the Advancement of Science, and a member of Sigma Xi, the American Astronomical Society, and the Royal Astronomical Society of Canada.

Besides her professional work in astronomy, Mayall had a lifelong interest in promoting the work of amateur astronomers, and especially in encouraging popular interest in astronomy at all levels. Perhaps her most widely recognized contribution to popular astronomy was as the co-editor, with R. Newton Mayall, of the revised editions of Olcott's *Field Book of the Skies*. She was also co-author with her husband of *Skyshooting, a book on photography for amateur astronomers*, and *Sundials and Their Construction, Astronomical Contribution and Significance*. In addition, Mayall edited and revised a new edition of **Thomas Webb**'s *Celestial Objects for the Common Telescope* that has remained in print since 1962.

In all, Margaret Mayall worked with devotion and dedication to firmly establish the AAVSO as an independent research organization. It is today the largest organization of variable star observers in the world. In recognition of her efforts, the AAVSO, in 1974, established the Margaret W. Mayall Assistantship in her honor to provide variable star research opportunities for young people at AAVSO headquarters. In 1957, the Western Amateur Astronomers awarded their G. Bruce Blair Gold Medal to Mayall for her contributions to amateur astronomy. The following year, Mayall was the recipient of the American Astronomical Society's Annie Jump Cannon Award. The IAU named minor planet (3342) Fivesparks in honor of Mayall and her husband Newton.

Michael Saladyga

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Mayall, Nicholas Ulrich

Born **Moline, Illinois, USA, 9 May 1906**
Died **Tucson, Arizona, USA, 5 January 1993**

Nicholas (Nick) Mayall, a 20th-century observational astronomer, produced major advances regarding the motions and compositions of globular clusters, established the Crab Nebula as the remnant of the supernova of 1054 that was described by the Chinese, studied the internal motions of two galaxies, and contributed to the measurement of the rate of expansion of the Universe. Mayall was also an effective observatory director for the construction, commissioning, and early years of operation of the Kitt Peak National Observatory.

Mayall was the son of an engineer, Edwin L. Mayall, Sr., and his wife Olive (*née* Ulrich) Mayall. They moved to near Modesto, California, where Mayall attended elementary school, and then to Stockton, California where he completed high school. Mayall entered the University of California College of Mining in 1924 but had to shift to another field because of his extreme color blindness. He selected astronomy and graduated in 1928. Mayall lived with and supported his divorced mother during this period by working in the university library.

Mayall then worked for 2 years (1929–1931) as a computer at the Mount Wilson Observatory assisting **Edwin Hubble**, **Alfred Joy**, **Walter Adams**, and **Seth Nicholson** by measuring and reducing their observational data. After Pluto was discovered by **Clyde Tombaugh** in 1930, Mayall and Nicholson found earlier photographs of it in the archives and produced the first definitive elliptical orbit of the planet. Mayall decided, on the basis of his experience at Mount Wilson Observatory, that he would pursue a career in astrophysics specializing in nebular spectroscopy. He earned a Ph.D. from the University of California at Berkeley in 1934 for a thesis suggested by Hubble, a census of galaxies as a function of galaxy brightness and area in the sky. Mayall's thesis advisor was **William Wright** who arranged employment for his protégé as an astronomer at the Lick Observatory.

To work on diffuse galaxies and globular clusters, Mayall designed an UV-transmitting spectrograph for the 0.9-m Crossley telescope. Using that spectrograph he determined the radial expansion of the Crab Nebula and along with **Jan Oort**, established that it was a remnant of the supernova first observed by the Chinese in 1054. He obtained measures of the internal rotation of the Andromeda Galaxy (M31) and the large spiral galaxy (M33) in Triangulum. Mayall then collaborated with his graduate school colleague, theoretician **Arthur Wyse** on the analysis of that data in 1942.

During World War II Mayall worked at the Radiation Laboratory in Cambridge, Massachusetts, the Office of Scientific Research and Development project at the Mount Wilson Observatory headquarters in Pasadena, California, and the California Institute of Technology rocket project in Pasadena and Inyokern, California.

After the war Mayall was deeply involved in obtaining a 3-m reflector (now called the Shane reflector in honor of **Charles Shane**) for the Lick Observatory; the telescope was not completed until 1960. Mayall continued to use the Crossley reflector to determine the motions of 50 globular clusters and showed that they shared only partly in the rotation of the star of the Galactic disk. With **Milton Humason** and others, Mayall obtained the redshifts of 800 galaxies. Humason used the 100-in. (2.5-m) and 200-in. (5-m) telescopes for the fainter galaxies while Mayall observed the brighter ones with the Crossley reflector. Perhaps in compensation for his color blindness, Mayall was able to see fainter objects through a telescope than other astronomers, *e.g.*, $V = 16$th magnitude with the 0.9-m Crossley Reflector. The data gathered by Humason and Mayall were analyzed by Allan Rex Sandage (born: 1926) to give a Hubble constant of 180 km/s/Mpc, a significant milepost on the way from Hubble's original value of 530 km/s/Mpc to the currently accepted value near 65–70 km/s/Mpc.

In 1960 Mayall became the second director of the Kitt Peak National Observatory [KPNO]. He oversaw the development of the site and the construction of the 4-m telescope (now called the Mayall telescope in his honor). What Mayall lacked in administrative experience (at first a liability) he more than made up through his ability to attract a first-class scientific staff because of his personal reputation as an outstanding research astronomer. Importantly, that reputation had been developed on the large telescopes at Lick Observatory, Mount Wilson, and Mount Palomar. When the Association of Universities for Research in Astronomy [AURA], the managing corporation for KPNO, took over the project from the University of Chicago, Mayall assumed responsibility for the early development of the Cerro Tololo Interamerican Observatory [CTIO] in Chile and the construction of the 4-m CTIO telescope (now called the Blanco telescope in honor of the first CTIO director, Victor Blanco).

Perhaps the most important of Mayall's contributions at KPNO was his leadership of a transition in style for major observatory management. Over strong recommendations to the contrary by the directors and staff at the Mount Wilson and Palomar observatories, Mayall guided the implementation of an organization designed to facilitate use of the major facilities at KPNO as community assets. He was a gentle director, knew everyone of 300 employees by first name, and was particularly effective in relations with the university administrators and the appropriate federal and state officials who oversaw KPNO.

Mayall had long suffered from diabetes and arthritis, and retired from KPNO in 1971 at the age of 65. Throughout his research career of nearly 30 years at the Lick Observatory he was a meticulous and outstanding observer of galaxies and clusters, and proved equally capable as the administrator of a large scientific institution.

Helmut A. Abt

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Mayer, Christian

Born **Meseritsch (Velké Meziříćí, Czech Republic), 20 August 1719**
Died **Heidelberg, (Germany), 17 April 1783**

The Jesuit astronomer Christian Mayer published the first catalog of stars that were close enough together, as seen through a telescope, that they might be considered double stars, and showed by comparison of some of these stars with **John Flamsteed**'s observations from the previous century that some possible orbital motion was detectable. Mayer could thus be considered to be the originator of the new and important field of double star astronomy. It was left to **William Herschel** to show, some two decades later, that some double stars might be linked gravitationally through his more accurate measures of stellar positions. Herschel demonstrated, with greater precision, possible motions on a shorter time frame.

Little is known with certainty of Mayer's early life except that in 1745 he entered the Jesuit order as a noviate in Mannheim, then capital of the Palatinate. Mayer taught languages and mathematics at the Jesuit school in Aschaffenburg and began active observational work in astronomy. In 1752, Mayer was appointed professor of mathematics and physics at Heidelberg University, and began publishing works in those fields but was soon concentrating his efforts on astronomy. Mayer's astronomical work eventually attracted the attention of Karl Theodor, Elector of the Palatinate, who was very interested in science. Karl Theodor first arranged for the construction of a small observatory at his summer residence in Schwetzingen and appointed Mayer state astronomer. A larger observatory was constructed in Mannheim, equipped with some of the finest instruments available from London instrument makers, the leaders in this field at the time. The new instruments included a great mural quadrant equipped with a telescopic site by Bird, installed in 1775, as well as other instruments by Dollond, Troughton, and Ramsden.

Mayer's work as an astronomer included much that was routine for the period, including participation in the measurement of a degree of the meridian with **César Cassini de Thury**, observation of the two transits of Venus from Russia, and the development of a map of the Russian Empire for Catherine II. But it was in his investigations of double stars that Mayer established his claim as a historical figure.

Ptolemy first applied the name double star to the bright naked eye pair ν^1 ν^2 Sagittarii, and in later years **Giambattista Riccioli** identified two such pairs in Capricorn and Hyades, while **Robert Hooke** noticed that γ Arietis was a telescopic double in 1665. **Jean Cassini** (Cassini I), **Giovanni Biachini**, and **Charles Messier** are all credited with recording the duplicity of one or more bright stars in subsequent years. By 1767, **John Michell** had concluded, on statistical grounds, that some of the many stars that appeared very close together telescopically might actually be gravitationally connected, but it was Mayer who first systematized the study of double stars. He first sent his lists of such stars to **Neville Maskelyne** for his comments, cataloging the right ascension and declination of various close pairs that to Mayer seemed candidates for closer observation.

Mayer published his first catalog of possible double stars in 1778. His claim that he had discovered stars with satellites was at first misinterpreted by astronomers and triggered a string of rebuttals from N. Fuss, **Maximilian Hell**, **Johann Bode**, and others who disputed the discovery of a planetary satellite of these stars. Herschel issued three catalogs of possible double stars in 1782, 1785, and 1821, listing a total of 848 examples of such pairs. Herschel's first catalogue was apparently published without prior knowledge of either Michell's or Mayer's previous efforts, but there was little overlap between the two lists of stars. It was not until Herschel reexamined his original catalog of double stars in 1802, and discovered that some of the companion stars had moved in such a way as to leave little doubt that the two stars were linked, that Michell's hypothesis and Mayer's empirical claims were given credibility. By then, also, Mayer had couched his terminology in such a way as to make clear that the coupling of stars and not planetary satellites was the object of his study. The English translation of his article in the *Transactions of the American Philosophical Society*, for example, discussed the companion stars as attendants rather than as satellites. In a table of 12 double stars in that article, Mayer supported his hypothesis by including Flamsteed's observations of eight stars from the previous century that seemingly demonstrated orbital motion had occurred over the intervening period.

Thomas R. Williams

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——— (1786). "Astronomical Observations." *Transactions of the American Philosophical Society* 2: 217–225.

Mayer, Johann Tobias

Born **Marbach near Stuttgart, (Germany), 17 February 1723**
Died **Göttingen, (Germany), 20 February 1762**

Selenographer Tobias Mayer prepared the earliest quantitative map of features on the surface of the Moon as well as lunar tables used by **Neville Maskelyne** in preparing early editions of the *Nautical Almanac*. Mayer was the son of a cartwright who left his trade in 1723 to work as foreman of a well-digging crew in Esslingen, Baden-Württemberg, where his family joined him a year later. Following the death of his father in 1731, Mayer was put into the local orphanage, and he taught himself mathematics from Christian von Wolff's *Anfangs-Gründe aller mathematischen Wissenschaften*. His mother found work in Saint Katharine's Hospital, which probably explains why Mayer came to prepare architectural drawings of the hospital at barely 14. His skill in this direction attracted the notice of a noncommissioned officer in the Swabian district artillery, then garrisoned in

Esslingen, under whose direction in 1739 Mayer produced a book on military fortifications; later that year he drew a map of Esslingen and its environs.

Mayer's first book, published around 1741, deals with the application of analytical methods to the solution of geometrical problems. His second, *Mathematischer Atlas* (1745), appeared in the period during which he briefly worked for the firm of Johann Andreas Pfeffel of Augsburg, Bavaria. Its choice of subject matter is a good index of the extent of Mayer's scientific knowledge at that time. On leaving Augsburg he joined the Homann Cartographic Bureau in Nuremberg, Bavaria, where he devoted 5 years to improving the state of mapmaking. Mayer collated geographical and astronomical data, and made observations of occultations and eclipses. He drew over 30 maps of which the Mappa Critica of Germany is considered the most significant, as it set new standards for handling geographical source materials and for applying astronomical data to the determination of latitude and longitude.

In 1747 and 1748 Mayer obtained a large number of meridian transits of the Moon, and made numerous measures of its angular diameter, to facilitate the lunar-eclipse method of fixing longitude. In addition to determining the selenographic coordinates of 89 major lunar markings, in doing so, he made allowance for the irregularity in the orbital motion and the libration of the Moon.

The *Kosmographische Nachrichten und Sammlungen auf das Jahr 1748* (Nuremberg, 1750), which Mayer edited for the newly formed Cosmographical Society, contains a description of his glass micrometer, his observations on the solar eclipse of 25 July 1748 and occultations of some bright stars, his major treatise on the lunar libration, and his consideration on why the Moon cannot have an atmosphere.

In early 1751, Mayer took a professorship at the Georg-August Academy in Göttingen. This was a nominal position, based solely on his reputation as a cartographer and practical astronomer. Shortly before leaving Nuremburg, he married Maria Victoria Gnüge, by whom he had eight children, of whom only three survived.

In 1752 Mayer drew up new lunar and solar tables, accurate to 1′. Comparing his positional values to historical observations (for instance, those made at all lunar and solar eclipses described since the invention of the telescope), he found that all discrepancies were attributable to errors in star places and the inferior quality of the instruments used. On the recommendation of **James Bradley,** Mayer's lunar tables, edited by **Nevil Maskelyne**, were used to compute the lunar and solar ephemerides for the early editions of the *Nautical Almanac*.

Mayer's further researches included elimination of errors from a 6-ft.-radius mural quadrant to be installed in Göttingen, the invention of a new method of calculating the circumstances of solar eclipses, the study of the proper motion of stars, and a catalogue of zodiacal stars. His works on each of these subjects were published posthumously in Georg Christoph Lichtenberg's *Opera inedita Tobiae Mayeri* (Göttingen, 1775). Appended to the book is a copper engraving of Mayer's map of the Moon. At 8 in. in diameter, it was the most accurate map of the visible lunar surface for half a century and was reproduced by **Johann Schröter** in his *Selenotopografische Fragmenten*.

Mayer's later work included efforts to improve land measurement, a method to find geographical coordinates independent of celestial observation. In 1765 his widow received £3,000 from the British government in recognition of her husband's claim, presented a decade earlier, for one of the prizes in connection with the quest to determine longitude at sea.

Much of the manuscript material relating to Mayer is preserved in Göttingen at the Niedersächsische Staats-und Universitäts-Bibliothek.

Richard Baum

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Mayer, Julius Robert

Born **Heilbronn, (Baden-Württemberg, Germany), 25 November 1814**

Died **Heilbronn, (Baden-Württemberg), Germany, 20 March 1878**

Julius Mayer independently established the principle of energy conservation, proposed a novel theory of the Sun's energy source, and considered the effects of tidal friction on the Earth–Moon system. Mayer was the youngest of three sons of the apothecary Christian Jakob Mayer and his wife, the daughter of a bookbinder. After attending Gymnasium at Heilbronn and an evangelical seminary at Schöntal, he began studies in the medical faculty at the University of Tübingen in 1832. Although he was expelled from the university in 1837 (for belonging to a secret student society), Mayer was allowed to take the state medical examinations and received his M.D. in 1838. After a short stay in Paris, he served as physician from 1840 to 1841 on a Dutch merchant ship that traveled to the East Indies. Following that experience, Mayer settled into a medical practice at Heilbronn. In 1842, he married Wilhelmine Regine Caroline Closs; the couple had seven children (only two of whom survived to adulthood).

During his oceanic voyage, Mayer undertook certain physiological observations that led him to speculate upon the conversion of food to heat in the human body, and on the resultant work that the body could perform. He concluded that heat and work are interchangeable, and this led him to reflect upon motion and heat as manifestations of a single, indestructible *Kraft* (force) in nature, which was quantitatively conserved in any conversion process. These ideas contained rudiments of the law of energy conservation. Soon afterward, Mayer extolled what later became known as the mechanical equivalent of heat. But he was not familiar with contemporary physical research and presented his ideas with a certain metaphysical style. Not surprisingly, his initial paper (1841) was rejected by the *Annalen der Physik und Chemie* (Annals of Physics and Chemistry). But after considerable reworking, Mayer's second paper, entitled "Bemerkungen über die Kräfte der unbelebten Natur" (Remarks on the forces of inanimate nature), was published in another journal, *Annalen der Chemie und Pharmazie* (Annals of Chemistry and Pharmacy), but went largely ignored. Nonetheless, Mayer anticipated to some extent the energy conservation principle later formulated by James Prescott Joule and **Herman von Helmholtz**, among others. Mayer's work was finally recognized after the former became engaged in a priority dispute. His views were later defended by Peter Guthrie Tait and some belated recognition at last came to him. In 1870, he was named a corresponding member of the Paris Academy of Sciences; in 1871, he received the Copley Medal of the Royal Society of London.

Mayer turned his theory of energy conservation upon two astrophysical problems. In 1846, he offered a novel explanation for the source of the Sun's heat. Mayer argued that its energy arose by the conversion of mechanical energy into heat, released during the Sun's continual bombardment by solid particles (meteors) attracted across interplanetary space. Though ultimately rejected, Mayer's idea may have influenced the creation of a successor theory of the Sun's heat by its gradual contraction.

Two years later, Mayer discussed the problem of tidal friction in his work, *Dynamik des Himmels* (Dynamics of the heavens, 1848). Here, he advanced a hypothesis by which the loss of energy and slowing of the Earth's rotation were roughly compensated by the planet's gradual contraction and acceleration. But like many of Mayer's speculations, this notion went largely unheeded by mainstream scientists. It is also wrong. Some of the energy heats the Earth, but the angular momentum is transferred to the orbit of the Moon, which is expanding at about 3 cm/year.

Mayer suffered bouts of depression that were exacerbated by family problems. But while he kept up his practice as a physician in Heilbronn, Mayer remained an outsider and dilettante when it came to his scientific work. He conducted few experiments and largely shunned mathematical analysis; he was primarily a conceptual thinker. Although his ideas regarding energy conservation were eventually accepted, they did not influence further developments in these subjects, which came from the works of others.

Horst Kant

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Mayr, Simon

Born **Gunzenhausen, (Bavaria, Germany), 20 January 1573**
Died **Ansbach, (Bavaria, Germany), 26 December 1624**

As court mathematician Simon Mayr was in charge of the Ansbach calendar, made the first telescopic observations of the Andromeda galaxy, and computed tables of the mean periods of the satellites of Jupiter more accurate than **Galileo Galilei**. Some sources state that his father Reichart Mayr was the *Burgermeister* (mayor) of Gunzenhausen, but most evidently Simon was from poor family, as in 1586 he went to the Margrave's school for talented poor boys. This school was established to train poor young men for the ministry. He stayed there until 1601 when he was appointed mathematician to the Margrave of Ansbach and was sent to Prague to study with **Tycho Brahe**. After Brahe's death he went to Padua to study medicine. Mayr returned to Germany in 1605 and was appointed mathematician and physician to the Margraves, Christian and Joachim Ernst, serving the rest of his life in that position.

An observatory was built for Mayr, but little is known about his instruments. According to Mayr's own account, he learned in 1609 from an artillery officer, Freiherr Hans Philip Fuchs, that a Dutchman had tried to sell him a telescope at the Frankfurt fair. Mayr grasped the concept and reproduced a telescope, which he used mainly to observe Jupiter. He claimed in a book printed in 1614, *Mundus Iovialis Anno M.DC.IX Detectus Ope Perspicilly Belgici* (The Jovian World, discovered in 1609 by means of the Dutch Telescope), that he had first observed Jupiter's moons in December 1609, a month before Galilei. Galilei fiercely accused Mayr of plagiarism. Disputes about the plagiarism case continued for centuries. In a long treatise by J. Klug, Mayr was accused as a plagiarist, while support for Mayr was presented by J. H. C. Oudemans and J. Bosscha. As a compromise, it was suggested by J. H. Johnson that Mayr probably saw the satellites of Jupiter before Galilei; however, he evidently did not comprehend their real nature until Galilei had published his account of their discovery and the explanation of their connection with the planet. Mayr discovered the variability of magnitudes of the satellites of Jupiter and gave them names – Europa, Io, Ganymede and Callisto – that are still in use.

Mayr was an independent discoverer of M31, the Andromeda nebula. *Mundus Iovialis* contains his telescopic observations of our neighbor galaxy. Mayr also published on the comet in 1596 (C/1596 N1) and was among the first to observe the "new star" in 1604.

Mihkel Joeveer

Alternate name

Marius

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Oudemans, J. A. C. and J. Bosscha (1903). "Galilée et Marius." *Archives néerlandaises des sciences exactes et naturelles*, 2d ser., 8: 115–189.

McClean, Frank

Born **Glasgow, Scotland, 13 November 1837**
Died **Brussels, Belgium, 8 November 1904**

Frank McClean invested heavily in both laboratory and telescopic spectroscopy, comparing the solar spectrum with numerous terrestrial elements. His spectrographic survey of all stars brighter than 3.5 magnitude in both the Northern and Southern Hemispheres was a useful resource for astrophysicists for several years. McClean was the first astrophysicist to detect oxygen in the spectra of stars.

This wealthy civil engineer and amateur astronomer was the only son of John Robinson McClean, M.P., F.R.S., a renowned civil engineer, and Anna (*née*) Newsam McClean. Educated at Westminster School and the University of Glasgow, McClean graduated as 27th wrangler in the mathematical *tripos* at Trinity College, Cambridge in 1857. After working in his father's engineering firm, and later as a shipyard and railway engineer, McClean retired in 1870 in order to concentrate on his scientific and artistic interests. He maintained a private observatory and laboratory at Ferncliffe near Tunbridge Wells. Unlike many gentleman scientists, however, McClean engaged no laboratory assistants.

In his private laboratory McClean started experimenting with electricity in coils. After the completion of an attached observatory in 1875, he could extend his work to solar observation as well as stellar spectroscopy. McClean used a direct spectroscopic eyepiece of his own invention that was later commercialized by John Browning. Intrigued with the possibilities, McClean mounted a heliostat on his roof around 1879 to guide the light of the Sun to a fixed 4-in. refractor and spectroscopic bench in his attic laboratory. Using this apparatus, he undertook studies of the composition of the Sun as well as the effect of the Earth's atmosphere on the solar spectrum.

In December 1888, McClean presented to the Royal Astronomical Society a portfolio of photographs, enlarged 8.5 times, of the solar spectrum from the Fraunhofer line D to A, corresponding in representational mode and approximate dispersion to **Anders Ångström**'s lithographed normal map. In a subsequent publication, McClean continued Ångström's numbering sequence, labeling his plates VII to XIII, counting from the section containing D towards the violet.

Ångström's instrument had been a Nobert grating; McClean used a grating by **Lewis Rutherfurd** with 17,296 lines to the inch and with a ruled surface of about 1.74-in. width. His "Photographs of the Red End of the Solar Spectrum" covered that half of the Sun's visible spectrum not included in **Henry Rowland**'s photographic map. McClean's photographs also included "subsidiary" exposures displaying "in the same sections, both the red spectrum of the second order as before, and also the overlapping green-to-violet spectrum of the third order." The purpose of these double spectra was to act as a reference for spectroscopists in the red part of the spectrum with third-order spectra, for lack of overlappings in the same order. Commendable as was this extension of Rowland's photographic map into the yellow–red region of the spectrum (5,800 to 7,700 Å), it had the serious problem of not being sufficiently enlarged. One set of portfolio enlargements, deposited in the library of the Royal Astronomical Society, was accessible to the London-based scientific community and, to some extent, to visitors from other parts of Great Britain, but it was not easily available to researchers elsewhere. The only published part of this series of photographs was a small segment of the spectrum around the line A at 7,600 Å. Technically speaking, though, this plate was not a photograph but a lithographed sketch by the assistant secretary of the society and highly skilled lithographer William Henry Wesley (1841–1922) – "taken from the photograph." The plate is misleadingly labeled "The A group of the solar spectrum. Photographed by F. McClean," thus ignoring Wesley's lithographic drafting, and mentioning only the printing company (E. Stanford in London). Wesley did a superb job in bringing out the beautifully striated structure of this line group and the nearly plastic appearance of some of the split lines. Yet this mixture of techniques clearly did not meet the purpose, which was to complete the map photographically.

This became moot with the appearance of Rowland's second series in 1889, which included the red extreme of the spectrum. In spring of that year, McClean once again appeared before the Royal Astronomical Society to present exposures of the solar spectrum, with "parallel photographs" of iron, iridium, and titanium, produced in the same manner. However, his next two spectrographic publications adopted the contemporary photomechanical reproduction technique, even though this amounted to surrendering his do-it-yourself principle, which he had rigorously followed up to that point. In late 1890 he published "Comparative Photographic Spectra of the high sun and Low sun from H to A Showing the Atmospheric Absorption Bands" (in a sense, the photographic analogue of **Louis Thollon**'s contemporary lithographic comparative map). In November 1891 McClean completed comparative photographic spectra of the Sun and 15 metals (including platinum, iridium, osmium, palladium, rhodium, ruthenium, gold, and silver, as well as manganese, cobalt, nickel, chromium, aluminium, and copper) for the wavelength region 3,800–5,750 Å. This map of metallic spectra, compiled with the aid of a plane Rowland grating acquired in 1890, was especially useful because it was the first to include the rare metals palladium, rhodium, and ruthenium.

In 1895, McClean began a systematic study of the spectra of all stars brighter than 3.5 magnitude using a 20° objective prism. Grubb and Sons produced a special telescope for his purpose based on the telescopic cameras manufactured by the firm for the Astrographic Catalogue and *Carte du Ciel* project. McClean's survey for the northern heavens was published in 1896. The following year McClean was invited to the Royal Observatory at the Cape of Good Hope by **David Gill** to complete his survey of the whole sky. For his work at the Cape, McClean took only the objective prism and mounted it on the Cape's *Carte du Ciel* telescope. The southern skies survey was published in 1898. In reviews in The *Astrophysical Journal*, McClean's spectral charts were criticized by **Edwin Frost** as "unprofessional" because McClean failed to properly document the instrument, dates, times, and conditions under which the spectra were recorded, all details deemed necessary for the interpretation of the stellar spectra. Frost also observed that the photographic quality of the southern charts was improved over those from the north. Notwithstanding Frost's criticism, however, the McClean charts were a resource to which some astrophysicists could turn for comparative data, pending availability of the Henry Draper Catalogue. Based on his photographic spectral survey, McClean proposed a stellar spectral classification scheme similar to that of **Angelo Secchi**, but with Secchi's first class subdivided into three types corresponding to the B, A, and F stars in the Henry Draper classification, a scheme that was beginning to find favor. Thus, McClean's system was never widely adopted.

The spectral survey work produced two important results. First, because McClean arranged the survey in terms of galactic coordinates rather than in the conventional sidereal format, it clearly demonstrated that the stars in McClean's first type, which he recognized contained the spectrum of neutral helium, were concentrated near the galactic plane. Also, during his work at the Cape, McClean recognized that the spectrum of β Crucis and other stars in his Type 1, which he also identified as "helium" stars, contained the spectral lines of oxygen. Gill was able to verify the oxygen identification with the large Cape spectrograph. However, McClean's discovery of stellar oxygen was received with guarded caution by other astrophysicists who recalled the major controversy over **Henry Draper**'s earlier claim to have discovered oxygen in the spectrum of the Sun. It was for that reason that when McClean received the Royal Astronomical Society Gold Medal in 1899, it was primarily for his stellar spectral survey work, though the discovery of oxygen in the stars might equally have merited such recognition.

Aside from his scientific accomplishments, McClean also furthered the cause of scientific research by donating several expensive instruments to various institutions, including the 24-in. Victoria telescope to the Royal Observatory at the Cape of Good Hope. He also endowed the Isaac Newton studentships at the University of Cambridge for the encouragement of study and research in astronomy and physical optics.

McClean was honored with an honorary LL.D. by the University of Glasgow in 1894. Elected to membership in the Royal Astronomical Society in 1877, McClean served on its council from 1891 until his death from pneumonia. His wife, Ellen (*née* Greg), bore him two daughters and three sons.

Klaus Hentschel

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McCrea, William Hunter

Born **Dublin, Ireland, 24 December 1904**
Died **Lewes, (East Sussex), England, 25 April 1999**

Irish–English mathematical astronomer Sir William McCrea is most widely known for work in modern, general-relativistic cosmology; he also helped to establish that the Sun and stars are made primarily of hydrogen and helium. McCrea was the eldest child of schoolmaster Robert Hunter McCrea and Margaret (*née* Hutton) McCrea. He attended elementary and grammar schools in Chesterfield, Derbyshire, winning an entrance scholarship in mathematics to Trinity College, Cambridge, and receiving a *tripos* degree in mathematics in 1926. McCrea's Ph.D. dissertation was completed under **Ralph Fowler** in 1930, after a year's visit at Göttingen University in Germany. His early work was largely on the application of mathematical methods to basic problems in quantum physics and relativity.

McCrea's academic appointments were as lecturer in mathematics at and the University of Edinburgh (1930–1932), reader in mathematics at Imperial College, London (1932–1936), professor of mathematics at Queen's University, Belfast (1936–1944). The last was interrupted by operational research in the British Admiralty, which he completed with the rank of captain. (The team was led by **Patrick Blackett**) McCrea was then Professor at Royal Holloway College, London (1946–1966), and, finally, the first research professor in theoretical astronomy at the recently established University of Sussex (1966–1972, and as an active emeritus professor for 25 years thereafter). Soon after the end of World War II, McCrea had been one of the strong advocates of a national center of theoretical astronomy. After much negotiation, the Astronomy Centre at the University of Sussex and the Institute of Theoretical Astronomy (under **Fred Hoyle**), which later merged into the overall Cambridge Institute of Astronomy, were the outcome of this. The best known of McCrea's students who remained in astronomy date from the Royal Holloway years and include Derek McNally, Gillian Peach, Michael

Rowen-Robinson, and Iwan Williams, most of whose careers were spent in London.

Two areas of McCrea's work had the longest, lasting impact on subsequent astronomical research. The first of these is cosmology. In 1933 he and **Edward Milne** of Oxford University showed that most general relativistic models of an expanding universe have close Newtonian analogs, which are somewhat easier to understand and within which approximate calculations can be done. McCrea was also the journal editor directly responsible for the acceptance of the first paper on steady-state cosmology (by Hermann Bondi and Thomas Gold) and was initially quite sympathetic to this alternative to an evolutionary universe; eventually he realized that it was in strong disagreement with observations. Late in life McCrea expressed doubts about all cosmological models (a trait he shared with **Grote Reber** and a number of other astronomers of his generation).

The other major area in which McCrea rightly receives credit is the demonstration that the Sun and stars are made mostly of hydrogen and helium. The 1925 Ph.D. thesis of **Cecilia Payne-Gaposchkin** reached this conclusion for K giants, but it was not widely accepted. Acceptance of the idea required calculations using more accurate treatments of the properties of hydrogen and other atoms and of the diffusion of radiation through ionized gases. European textbooks most often credit **Carl von Weizsacher**, American texts **Henry Russell**, British texts McCrea (particularly his work on the solar corona before 1931), and a case can perhaps also be made for **Bengt Strömgren**. The final step, showing that the main obstacle to the free passage of light through the outer layers of the Sun is due to hydrogen atoms with a second electron temporarily attached, was taken by **Ruper Wildt** in 1947.

McCrea was also an early proponent for a binary star model of the origin of blue stragglers (stars which appear to be younger than the populations around them) and came to be regarded as a source of last resort for mechanisms to explain or measure effects that otherwise defied the community, along the lines of, "Well, if Bill can't think of a way to measure the cosmological constant independent of the other cosmological parameters, perhaps it can't be done." (Actually it can.) Some of the ideas McCrea put forward, for instance accounting for the most massive stars by accretion of gas onto ones like the Sun, and mechanisms for formation of hydrogen molecules, were indeed prompted by observations most of his contemporaries thought inexplicable.

Knighthood came relatively late in McCrea's life, in 1985, long after honorary degrees from universities in Ireland, England, and Argentina, and academy memberships in Belgium, Italy, Scotland, and England. His service to the Royal Astronomical Society [RAS] (whose Gold Medal he received in 1976) was remarkable. McCrea held all four of the major offices, secretary (1946–1949), president (1961–1963), foreign Secretary (1968–1971), and treasurer (1976–1979), as well as editorships of the RAS's *Monthly Notices* and *Observatory* Magazine. He married Marian Nicol Core Webster in 1933, and was a lifelong communicating member of the established Anglican Church.

George Gale

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McIntosh, Ronald Alexander

Born **Auckland, New Zealand, 21 January 1904**
Died **Auckland, New Zealand, 17 May 1977**

An accountant, and then journalist by profession, Ronald McIntosh distinguished himself as an amateur observer of meteors and also as a computer of meteor orbits and radiants. He was self-trained in mathematics and celestial mechanics. An internationally recognized authority, McIntosh's published papers (numbering over 100) served as the standard reference works on Southern Hemisphere radiants and meteor rates between 1925 and 1945, and still remain, along with more recent radar studies, among the most reliable sources of such information. The importance of his contributions was frequently acknowledged by **Charles Olivier** of the American Meteor Society. Elected a fellow of the Royal Astronomical Society, and of the International Astronomical Union's Commission 22 on Meteors, McIntosh twice was awarded a Donovan Prize and Bronze Medal from Australia for his contributions to astronomy. He was also a popular lecturer at the Auckland Planetarium for a number of decades and served as secretary of the Auckland Observatory and Planetarium Trust Board. McIntosh was married and had two children.

Thomas R. Williams

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McKellar, Andrew

Born **Vancouver, British Columbia, Canada, 2 February 1910**
Died **Victoria, British Columbia, Canada, 6 May 1960**

Canadian stellar astronomer Andrew McKellar is best remembered today for his accidental discovery (not at the time understood) of the cosmic microwave background, which is perhaps the strongest evidence for a Big-Bang universe (one that had a very hot, dense state about 15 billion years ago). The discovery came in the form of the measurement of the temperature of CN molecules (really radicals) in the interstellar medium. He found this to be about 2.3 K, with the result being confirmed the next year by **Walter Adams**.

Andrew McKellar was the son of John Hamilton McKellar and Mary Littleson of Scotland. Andrew married Mary Belgrave Crouch in 1938, and they had two children, Andrew Robert and Mary Barbara.

McKellar took an honors BA in mathematics and physics at the University of British Columbia in 1930, followed by graduate work in physics at the University of California (MA: 1932, Ph.D.: 1933). During this time, he was a student assistant at the Dominion Astrophysical Observatory. With a fellowship from the United States National Research Council, he spent 2 years at the Massachusetts Institute of Technology (1933–1935). During World War II, McKellar taught physics at the University of British Columbia (1941/1942), followed by service in the Royal Canadian Navy in operational research (1944/1945), for which he was awarded an MBE in 1947. He also spent a year as visiting professor of astronomy and physics at the University of Toronto (1952/1953). Most of McKellar's career, from 1935 until his death, was at the Dominion Astrophysical Observatory.

McKellar was an associate editor of the *Astrophysical Journal*. He served as president of the Royal Astronomical Society of Canada (1959/1960), the Astronomical Society of the Pacific (1955–1957), and the International Astronomical Union Commission on Comets. He was also active in the American Astronomical Society and was a fellow of the Royal Society of Canada.

McKellar was a leading figure in the development of molecular spectroscopy in astronomy. He determined the $^{12}C/^{13}C$ ratio in carbon stars to be 5:1, very different from the terrestrial ratio; this evidence supported the idea of a CNO- cycle hydrogen fusion is stars. He detected the molecules CH, CN, and NaH in interstellar space in 1940, realizing that their spectra in space is altered from the laboratory form due to extreme conditions. His analysis of cometary spectra showed that solar radiation is the cause of excitation of cometary molecules. Before his death, McKellar studied the chromospheres of giant stars spectroscopically by observing eclipsing binaries.

At the time of McKellar's death, the importance of his measurement of the interstellar temperature had not yet been appreciated. Both he and his contemporaries would have agreed with the judgement of **Gerhard Herzberg** that it had "of course a very restricted meaning."

Richard A. Jarrell

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McLaughlin, Dean Benjamin

Born **Brooklyn, New York, USA, 25 October 1901**
Died **Ann Arbor, Michigan, USA, 8 December 1965**

American stellar spectroscopist Dean McLaughlin participated in the discovery that stars in general rotate like the Sun and that members of close binary systems are often rapid rotators. He was the son of Michael Leo Benjamin and Celia Elizabeth Benjamin McLaughlin. In 1927, he married Laura Elizabeth Hill, with whom he had five children. McLaughlin received all his degrees from the University of Michigan, BA (1923), MS (1924), and Ph.D. (1927), the last for the analysis of spectra of eclipsing binaries, under the guidance of **Ralph Curtiss** and **Richard Rossiter**. They recognized that, just before the brighter star is fully eclipsed, rotation will give the uneclipsed segment of the star an additional motion away from us, leading to an asymmetrical line profile. This is still sometimes called the McLaughlin effect or the Rossiter–McLaughlin effect.

McLaughlin served as an assistant in the Michigan astronomy department from 1922 to 1924 and then became instructor of mathematics and astronomy at Swarthmore College, from 1924 to 1927. In 1927 he returned to Ann Arbor as assistant professor of astronomy, was promoted to associate professor in 1934 and professor in 1941, and remained at Michigan for the remainder of his career. He participated in the Swarthmore College solar eclipse expedition to Sumatra in 1926 and in the Michigan expedition to Fryeburg, Maine in 1932. When World War II broke out, the McLaughlins moved to Massachusetts for 3 years while he served in the Radiation Laboratory of the Massachusetts Institute of Technology, working on radar problems. In 1940, 1951, and 1958 he was a guest observer at the Mount Wilson, Mount Palomar, and Lick observatories. McLaughlin had a great interest in field geology, and from 1951 until 1965 his summers were spent as a cooperating geologist in the Pennsylvania Topographic and Geologic Survey.

McLaughlin was a fellow of the American Association for the Advancement of Science, the Geological Society of America, and the American Astronomical Society, which he served as secretary from 1940 to 1946. He also belonged to the International Astronomical Union, the Astronomical Society of the Pacific, the Michigan Academy of Science, Arts, and Letters, the Michigan Geological Society, the Pennsylvania Academy of Science, and Sigma Xi.

After the death of Curtiss in 1929, McLaughlin directed the Michigan spectrographic programs. A careful, diligent spectroscopist, McLaughlin used Michigan's 37.5-in. reflecting telescope and spectrographs for 40 years under increasingly difficult circumstances, as the university and city encroached on the observatory. His research continued Curtiss's work on the atmospheres of Be stars, bright stars with emission lines of hydrogen in their spectra, and on peculiar variable stars. McLaughlin also became an authority on the spectral characteristics of novae; he devoted much time to unraveling their problems after an unprecedented run of good weather and seeing allowed him to create an excellent photographic record of Nova Herculis 1934. McLaughlin's expertise allowed him to observe and measure many obscure lines on the plates. He also combined spectroscopic with photometric observations.

McLaughlin was known for his good humor and gifts as a teacher and colleague. He also took part in efforts to popularize astronomy and wrote many general articles for *Popular Astronomy*, beginning as an undergraduate at Michigan. In 1961 he published an introductory textbook based upon his courses, and in 1965 he coedited a standard handbook on astrophysics with his Michigan colleague **Lawrence Aller**. The textbook was the immediate precursor of those written starting about 1970 and meant specifically for nonmajor courses in astronomy, and was widely used for general astronomy courses in the 1960s.

In the 1950s McLaughlin's geological researches led him to propose a new theory to explain the appearance of the surface features of Mars, based upon the effects of wind and volcanic activity. His ideas have found more favor in recent years, thanks to observations from space-borne vehicles. His geological researches in the United States led to studies of Triassic era rocks in Pennsylvania and New Jersey and of the pre-Cambrian in Canada.

The University of Michigan observatories had established a tradition of careful observational spectroscopy, beginning with Curtiss and W. Carl Rufus. McLaughlin and his students continued that tradition, specializing in peculiar stars, variables, and novae. McLaughlin chose important problems that lay, however, within the capabilities of the Michigan equipment; he developed a large and consistent body of observations, and he wrote studies that included not only the observational data but also shrewd interpretations. With his colleagues, Curtiss at first and later with Aller, he kept the Michigan graduate program going strong. He was a productive, respected, and significant astronomer throughout his 40-year career.

A number of records are in the Michigan Historical Collections, Bentley Library, The University of Michigan.

Rudi Paul Lindner

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McMath, Robert Raynolds

Born **Detroit, Michigan, USA, 11 May 1891**
Died **Bloomfield Hills, Michigan, USA, 2 January 1962**

As the founder and long-time director of the McMath–Hulbert Solar Observatory [MHSO], Robert McMath enjoyed a second career in astronomy following a successful career in engineering and industrial management. Organizational skills learned in his business career served McMath and astronomy well as he led the American Astronomical Society as its president, and guided the foundation of the Association of Universities for Research in Astronomy [AURA]. McMath served as the first president and as chairman of the AURA board of directors during the early phases of the development of the Kitt Peak National Astronomical Observatory.

McMath, the son of Francis Charles and Josephine (*née* Cook) McMath, enjoyed a privileged childhood earning nearly a full year of advanced standing credits at the prestigious private Detroit University High School. He received his BCE from the University of Michigan in 1913. During and immediately after college McMath worked as a draftsman with the Canadian Bridge Company and in 1914 joined the Saint Lawrence Bridge Company as an assistant engineer; both companies were founded by his father. Anticipating the importance of aviation in World War I, already raging in Europe, McMath took flying lessons and qualified as a pilot before volunteering for service as a commissioned officer in the army. His assignment, however, was as a civil engineer building air bases for the Army Signal Corps's fledgling Air Service. Discharged with the rank of major but in poor health and on the verge of a nervous breakdown from overwork during the war, McMath recuperated for a period, before becoming general manager of Biltmore Forest Estates Company, a North Carolina real estate venture in which his father was an investor. There, during 1921 he met and married a young widow, Mary Ridgley (*née* Rodgers) Garrison, daughter of a vice president of the DuPont Company. They had a daughter, Madeline.

McMath joined Motors Metal Manufacturing Company [MMMC] the next year as assistant manager with explicit instructions from his father, a major stockholder in the firm, to assist in the liquidation of the nearly bankrupt company. McMath's preliminary assessment was that the firm could be salvaged, so he returned the company to profitability, remaining with MMMC or its successors for the remainder of his business career. McMath rose successively to vice president and general manager (1922), president (1925), and chairman of the board (1928–1954).

At an early age, McMath developed an interest in photography that coincided with a long-term family interest in astronomy. His father and grandfather both pursued astronomy as an avocational interest that spun off their training as surveyors in their careers in civil engineering. At the urging of his father, McMath took up astronomy intending to combine that interest with photography. As amateur astronomers, they participated in a solar-eclipse expedition on 24 January 1925, planning to observe the eclipse from a balloon with Detroit probate judge Henry Schoolcraft Hulbert (1869–1959). This plan had been recommended by **William Hussey**, then director of the University of Michigan's Observatory. Although the balloon ruptured during the inflation process, high winds would likely have otherwise prevented the proposed flight. This aborted attempt was only the first of an extended series of astronomical projects undertaken by the McMaths with Judge Hulbert.

In August, 1928 McMath made his first effort combining photography with astronomy. Holding a spring-driven camera between his stomach and the eyepiece of a 4-in. refracting telescope guided manually, he attempted to photograph sunrise in the Moon's craters. While the resulting frames showed decreasing shadow lengths, the quality of the images was not what McMath desired. When, at Judge Hulbert's suggestion, the University of Michigan astronomy department came to MMMC for help in fabricating the mounting for a new telescope, McMath met **Ralph Curtiss**, the new director of the University of Michigan's Detroit Observatory and chair of the astronomy department. Curtiss was impressed by the lunar sunrise film; he decided to join with the McMaths and Hulbert in creating time-lapse motion pictures of celestial objects. They designed a special 10.5-in. Newtonian reflecting telescope mounted on essentially the same mounting that MMMC fabricated for the Detroit Observatory that was completed in 1930 and housed in a dome at McMath's summer place on Lake Angelus near Pontiac, Michigan. At the suggestion of **Heber Curtis**, who was appointed head of the astronomy department following the untimely death of Curtiss, this observatory was named the McMath–Hulbert Observatory with Robert as director, a position he held until 1961.

The 10.5-in. telescope, which utilized the best mechanical and electrical engineering practices of the time, was designed to make time-lapse celestial motion pictures. It was likely the first equatorially mounted telescope that used continuously changing driving rates in both hour angle and declination. The highly refined tracking system eliminated annoying sudden motions of the image caused by manual tracking of an astronomical object during time-lapse photography. By 1931, the telescope could accurately follow the Moon or any other astronomical object smoothly without manual tracking. Curtis arranged to have McMath present films of the Moon and the satellites of Jupiter at a meeting of the National Academy of Sciences held in Ann Arbor in 1932. The films were widely acclaimed as educational tools and were distributed for many years by the *Encyclopedia Britannica*.

In December, 1931 the McMath–Hulbert Observatory was formally deeded to the University of Michigan. McMath, his father, and judge Hulbert were declared honorary curators for the new asset of the university's astronomy department. The telescope was then modified to take time-lapse photographs of solar prominences in the light of, for example, the K-line of calcium. The human eye cannot easily follow the slow changes on the Sun. But the McMath–Hulbert time-lapse technique speeded up the action by some 300 to 600 times, thus giving for the first time a dynamic presentation of solar activity. It was in these films that astronomers became aware that solar prominences originated above the surface of the Sun and flowed back into the Sun, rather than the reverse as had previously been believed.

To further pursue this work, McMath designed and constructed a 50-ft. solar tower telescope that was completed in 1936, with technical assistance from the Mount Wilson Observatory. **Edison Pettit** of the Mount Wilson staff spent three summers at the McMath–Hulbert Solar Observatory using these innovative new instruments. Later McMath designed and had built a 70-ft. tower telescope and a 24-in. Cassegrain reflector. These were not quite ready for operation when World War II broke out. Funding for these projects came from a variety of sources including family members, industry, private foundations, and the university.

Efforts at the McMath–Hulbert Observatory from 1942 until 1946 were devoted to various wartime projects. McMath worked principally with the Office of Scientific Research and Development and was awarded the President's Medal of Merit in 1948 for his accomplishments. Among the developments at the observatory was an instrument that McMath designed and built to observe in the near infrared with a Cashman lead-sulfide photocell, a product of World War II research, or a lead-telluride photocell. By connecting each to a recorder, McMath and the observatory staff were able to conduct spectral investigations in the infrared to study conditions in the atmospheres of both the Earth and Sun. In 1945, McMath was appointed professor of solar physics in the University of Michigan Astronomy Department.

After the war, research at the McMath–Hulbert Observatory continued with a vacuum spectrograph to make highly refined Doppler velocity measurements of motions within various solar features. The observatory staff included **Leo Goldberg**, **Orren Mohler**, Helen Dodson-Prince (1905–2004), and Austin Keith Pierce (1918–2005). McMath was appointed professor of astronomy in 1951, and retired as professor emeritus of astronomy, from the University of Michigan in 1961.

As president of the American Astronomical Society (1952–1954), McMath was asked to chair the National Science Foundation's [NSF] advisory panel for the National Astronomical Observatory [NAO]. It was an inspired choice on the basis of McMath's eclectic interests in business, engineering, and science, and his government service. From his wartime governmental service, McMath was acquainted with many influential individuals in Washington. Among his friends were Alan Waterman, the director of the NSF, former Michigan congressman Joseph Dodge, director of the Bureau of the Budget, and Paul Klopsteg, associate director of the NSF.

Prior to the first meeting of the NAO panel, McMath developed detailed plans for site surveys using 100-ft. towers to automatically record seeing at possible sites for the new observatory. Both daytime and nighttime seeing was considered reflecting McMath's hope that the site might include a large, modern solar telescope. By the fourth panel meeting in February 1956, site selection was well underway and a lengthy discussion of the observatory's organization took place. Additional details were discussed a year later when seven universities joined forces to form AURA. The association, selected by the National Science Board in May 1957 to construct and operate a national optical observatory, was officially incorporated on 28 October 1957 with McMath as its first President. When ill health caused him to relinquish many of his responsibilities, McMath was appointed chairman of the AURA board.

The need for a very large solar telescope was debated in the following year. At a meeting in September 1958, the AURA executive committee approved McMath's action in sending a revised solar telescope proposal to NSF. By late November, some 9 months after the decision to build the observatory on Kitt Peak, the solar telescope project, with Keith Pierce in charge, was added to the ongoing construction program.

McMath died before the solar telescope dedication in November 1962, when by resolution the AURA board, the instrument was officially named the Robert R. McMath Solar Telescope. Some 30 years later it was rededicated as the McMath–Pierce Solar Telescope.

At the 1961 annual AURA meeting, McMath suggested that plans be made for the construction of a 150-in. optical telescope. The resulting 158-in. reflector was dedicated in 1973 as the **Nicholas Mayall** telescope in honor of Mayall's long service as the second director of Kitt Peak National Observatory.

McMath served the American astronomical community ably and well during this crucial time, in which the emphasis was changing from individual projects to those of a team, and received many honors recognizing that service. He was awarded an honorary AM by his *alma mater* in 1933, and honorary DSc's in 1938 by Wayne State University, and by Pennsylvania Military College 3 years later. McMath received the John Price Witherill Medal of the Franklin Institute, Philadelphia in 1933, the Rittenhouse Medal of the Rittenhouse Astronomical Society in 1936, and the Society of Motion Picture Engineers Journal award, 1940. Two years later he was elected a fellow of the American Philosophical Society and of the National Academy of Sciences in 1958.

Many of McMath's papers are held among the Michigan Historical Collections of the University of Michigan's Bentley Historical Library. A valuable autobiography exists in the personal file at the National Science Foundation in Washington, DC.

George S. Mumford

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McVittie, George Cunliffe

Born **Smyrna (Izmir, Turkey), 5 June 1904**
Died **Canterbury, Kent, England, 8 March 1988**

British mathematician and relativist George C. McVittie made important contributions toward the problem of comparing the predictions of different general relativistic models of the Universe with observations. He was the son of a British merchant father and an Alsatian mother, born in a largely immigrant community that also included Jason Nassau (later director of the Warner and Swasey Observatory, CaseWestern Reserve University, Cleveland, Ohio, USA). With his brother, McVittie was home-schooled, developing an interest in both astronomy and Turkish archaeology. The family was on holiday in England in the summer of 1922 when a change in government in Turkey led to the sacking of Smyrna and the destruction of their home. None of them ever returned. After a spell helping his father, McVittie won a bursary and entered Edinburgh University in 1923 to study mathematics and natural philosophy. Profiting from the excellent teaching of Sir **Edmund Whittaker** and Charles Darwin, he progressed with high honors and scholarships to his master's degree.

In 1927, McVittie started research on the Maxwell–Einstein equations under the supervision of Whittaker. In 1928, he moved to Cambridge University where he received his only formal training in astronomy and, working under **Arthur Eddington,** completed a Ph.D. dissertation on unified field theories (the attempt to unify electromagnetism and general relativity, the theory of gravity, into a single set of equations) in 1930. He failed, but as did Einstein, who persisted in the attempt until near his death. In 1930, McVittie began work (part of it in collaboration with **William McCrea**) on the fate of density perturbations in a nearly homogeneous, static universe and then turned to the fate of condensations in an expanding universe, which grow more slowly than those on a static matrix – but still grow, so that galaxies indeed do form!

McVittie, held academic positions at Leeds (1933/1934), Liverpool (1934–1936), and London (a readership at King's College 1936–1948 and a professorship at Queen Mary College 1948–1952). Between 1939 and 1945 McVittie was seconded to Bletchley Park to work on deciphering of meteorological information from enemy territory and to attempt to restore accurate weather forecasting of the sort that had previously depended on international cooperation. The work of his group was enormously successful; he visited both the United States and Canada (an essential collaborator in receiving and decoding Japanese meteorological information) helping to establish their programs. McVittie was awarded the OBE for this work. Some of it was later published in meteorological journals.

During his London years, McVittie was one of the editors of *The Observatory* and of the *Quarterly Journal of Mechanics and Applied Mathematics*. He also gave some attention to **Edward Milne**'s theory of kinematical relativity, but soon concluded that the Einsteinian theory had a better chance of describing the observed universe. McVittie's 1937 book, *Cosmological Theory*, began the process of asking how valid comparisons between data and theory might be made on the scale of the whole Universe. At London, he was an inspiration to the young Arthur C. Clarke (among many other students) and served on the council of the Royal Astronomical Society.

In 1952, McVittie made big changes in both his personal and professional life, when he and his wife Mildred moved to Urbana, Illinois, USA. He became professor and head of a moribund Department of Astronomy at the University of Illinois. In the 20 years he was in Urbana, McVittie built the department into a thriving research school, with both optical and innovative radio telescopes. This suited his interest in comparing astronomical and cosmological theory with experiment; he kept in close touch with the wealth of new ideas and observational discoveries that emerged in the discipline during his time at Urbana.

McVittie's monograph *General Relativity and Cosmology* (1955, 1964) belongs to the Urbana period. Comparison of the two editions is particularly interesting. The first had described cosmological observations in terms of time and distance, using formulae that were linear approximations to the equations of general relativity and appropriate only for nearby objects. The advent of radio astronomy and discovery of much more distant galaxies and quasars prompted him to recast the entire discussion in terms of exact equations in the only directly measurable quantity, redshift, in the second edition.

In 1961, McVittie became secretary of the American Astronomical Society, holding the office until 1969. He was the last person to run the society on a part-time basis. Toward the end of his tenure, he helped oversee a number of difficult transitions, including the establishment of subdisciplinary divisions, transfer of the ownership of the *Astrophysical Journal* from the University of Chicago to the society, and the transformation of the Annie J. Cannon Prize to a research award. In curious irony given his birthplace, McVittie was by then a conservative voice counterbalancing the "young Turks." He also managed a series of publications on steady-state cosmology (which he never really believed in), stellar statistics, gravitational collapse, and the redshift-distance relationship.

On his retirement in 1972, the McVitties moved to Canterbury, England, where the University of Kent welcomed him as honorary professor of theoretical astronomy. The word "honorary" rapidly became a misnomer; he began teaching astronomy for the natural scientists and general relativity for the applied mathematics group, which he joined. McVittie supervised several mathematics doctoral students, including D. L. Wiltshire, R. P. A. C. Newman, and G. G. Swinerd, who produced important results. Also, 50 years after his 1933 paper, he published a solution of the nonlinear differential equation [NLDE] arising from a cosmological model. It is a quirk of history that his 1983 paper has eventually led to the formation of a very strong NLDE group within applied mathematics at Kent.

Some books on differential geometry offended McVittie's sense of orderliness and clarity of thought, and in the last year of his life McVittie turned to Clifford algebra as a vehicle for understanding gravitation at elementary-particle level. Up to a week before his death in March 1988, he was working on a fourth-order generalization of Einstein's equations, based on the Clifford algebraic approach.

In Canterbury, McVittie rediscovered his love for archaeology and played an active part in the Canterbury Archaeological Trust, of which he was treasurer from its foundation in 1976. He was elected to the Royal Society of Edinburgh (but not that of London). Minor planet (2417) McVittie was named for him.

J. S. R. Chisholm

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Méchain, Pierre-François-André

Born **Laon, (Aisne), France, 16 August 1744**
Died **Castellón de la Plana, Spain, 20 September 1804**

Pierre Méchain discovered and computed orbits for many comets and participated in important surveys and other geodesic work in France. As the son of a humble architect, Méchain spent his formative years in his native town. His talents eventually led him to attempt a course of study at the prestigious École des Ponts et Chausées. Because of lack of funds Méchain was forced to leave the school in order to earn his living as a private tutor. A small telescope that he handed over to his father to help the latter through some financial embarrassment brought the young man to an astronomer's attention. His father sold the telescope to **Jérôme Lalande** who then took the younger Méchain under his wing. Méchain owed his career as an astronomer to Lalande. Thanks to this patronage, Méchain obtained his first scientific employment in 1772, being appointed hydrographer in the Dépot de la Marine, the French navy's cartographic service, at first in Versailles and then in Paris. During the course of this work he gained experience in drawing maps, as well as in the determination of latitudes and longitudes on land.

Méchain also specialized privately in the search for comets. This met with success with the discovery of two comets in 1781 and the suggestion that **William Herschel**'s planet, initially taken to be a comet, had a circular orbit. The following year, by calculating the orbits, he showed that two comet apparitions, those of 1532 and 1661, did not correspond to the same comet, as had been the general opinion until then. This work earned Méchain an award from the Académie des sciences and his election as a member of that institution.

Once started on the pursuit of comets, Méchain soon became the most famous comet-hunter in France, securing his reputation by the discovery of up to nine more comets in subsequent years, and also through the calculation of the orbits for all comets for which he had sufficient knowledge. Based on his reputation as an orbital calculator, Méchain took charge of the preparation of the *Connaissance des Temps*, the French yearbook of astronomical ephemerides, which he edited between the years of 1788 and 1794. His work as a cometary observer necessarily led him to discover other new nebulous objects, which were included by **Charles Messier**, also a famous comet-hunter, in his well-known catalogue.

Méchain's experience in cartography and his status as a member of the Académie des Sciences, led to his selection, with **Jean-Dominique Cassini** and a young mathematician, **Adrien-Marie Legendre**, for a major geodetic task, linking the Paris Observatory and Greenwich Observatory by a great triangulation chain. This operation resulted in a confrontation between two different methods of geodetic surveying. The British, under general Roy, used the well-known portable quadrant, whereas the French tried a new instrument, invented by another academician, **Jean Charles de Borda**, which later became known as the repeating circle. Publication of the results, which was delayed until 1791 by the bellicose tension between France and Britain, was to be Méchain's first major astronomical/geodetic work.

When the French National Assembly decided to create a new standard of measurement, based on nature, and accepted the definition of the meter proposed by the Académie des sciences, Cassini, Legendre, and Méchain were again selected to undertake a major geodetic operation, the measurement of the arc of the meridian between Dunkerque and Barcelona.

In the end, it was Méchain and **Jean Delambre** who were in charge of the operation, which was, in time, to lead to Méchain's death. Between 1792 and 1798, Méchain and Delambre carried out both geodetic and latitude measurements on both French and Spanish territory. These they presented at the International Conference that met in Paris in 1799 to establish the decimal metric system; the results were published in *Base du système métrique décimal* (Paris, 1806–1810).

In 1798, Méchain was elected a member of the Bureau des longitudes, the organization set up to oversee French astronomical observatories and operations; he went on to hold the most important institutional positions in astronomy in France. On 10 September 1798, the bureau appointed him as as *Capitaine Concierge* of the Paris Observatory. On 8 June 1801, he was entrusted with the functions of the director of the observatory, and on 5 December of that year he was nominated as president of the Bureau des longitudes. Méchain remained in this post until 31 August 1802 when the bureau decided to extend geodetic operations in Spain to link the Balearic Islands with the Spanish coast and extend the Dunkerque–Barcelona arc by 3° towards the south.

Appointed as the person responsible for this work, Méchain left Paris on 26 April 1803. He carried out various subsidiary projects and made numerous terrestrial and latitude determinations both on the mainland and in the Balearic Islands. Méchain's death from malaria interrupted the work, which was completed between 1806 and 1808 by **Jean Biot** and **François Arago**.

Antonio E. Ten
Translated by: *Storm Dunlop*

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Mee, Arthur Butler Phillips

Born **Aberdeen, Scotland, 21 October 1860**
Died **Cardiff, Wales, 15 January 1926**

Amateur astronomer Arthur Mee, an author, journalist, and educator, combined an interest in planetary observation with organizing and coordinating astronomical activities, particularly in Wales. He was the son of George S. Mee, a pastor in the Baptist Church, and of Elizabeth (*née* Phillips) Mee. His father left the ministry to become a journalist, eventually settling in Llanelli in Wales, where Arthur spent his early years. Mee followed his father into journalism, first in Llanelli, where he married Claudia Thomas in 1888. He moved to Cardiff in 1892 to work in the *Western Mail* newspaper, for which he continued to work until his death, serving for many years as an assistant editor. He was best known professionally as a newspaper columnist.

Mee developed an early interest in astronomy and was active as an observer from the age of 17. He was noted for his visual observations with his 8-in. reflecting telescope, particularly of the Moon and Mars. He made many drawings of lunar features; these and his other observations, especially those of sunspots, meteors, and eclipses, were regularly published in amateur scientific journals. **Camille Flammarion** included some of Mee's drawings in his book *La Planète Mars*. On 11 March 1892, Mee observed Saturn with his 8-in. telescope. He was surprised to see the shadow of Titan on the disk and the satellite itself in transit a short distance away; he claimed to have been the first person to observe both simultaneously.

Shortly after moving to Cardiff, Mee founded the Astronomical Society of Wales, becoming its first president. For two decades, he edited its journal, its almanac, and later its magazine, *The Cambrian Natural Observer*. For a time, the society had over 200 members, with its publications relatively widely distributed. Through these activities, Mee was noted for his efforts to coordinate the activities of amateur astronomers and to publish their observations. He consequently had a pivotal role in Welsh amateur astronomy for the three decades preceding his death.

Mee encouraged amateur astronomers, and was prominent in popularizing astronomy as a public lecturer and as a writer. He published the book *Observational Astronomy* and the booklet "The Story of the Telescope." Mee was instrumental in arranging the gift of a 12-in. reflector as a public observatory to the city of Cardiff. He later donated his own telescope to the astronomical society in the nearby town of Barry.

Arthur Mee was known as a quiet, diffident man, short in physical stature. He was noted for his sense of humor, as is clear from his own entry in the book *Who's Who in Wales*, which he himself edited. He stated that in his early years he was intended for the medical profession, but "saved many lives by becoming a journalist." Mee developed widespread interests alongside astronomy, including history, natural history, languages, literature, and geography. He published several books, pamphlets, and articles on a diverse range of subjects, often writing under the *nom-de-plume* "Idris." He has occasionally been mistakenly confused with the English author Arthur Henry Mee, editor of the *Children's Encyclopaedia*.

Arthur B. P. Mee was suddenly taken ill and died of heart failure, survived by his wife. The crater Mee in the southern uplands of the lunar nearside commemorates him.

J. Bryn Jones

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Megenberg, Konrad [Conrad] von

Born **probably (Germany), *circa* 1309**
Died **Regensburg, (Bavaria, Germany), 14 April 1374**

Konrad von Megenberg translated **John of Holywood's** (Sacroboscö's) *Sphere*, the standard primer on astronomy and cosmology from the early 13th to the 17th century in the Latin West, into German. His *Die deutsche Sphaera* and his *Buch der Natur*, a translation of the influential *De natura rerum*, one of the earliest works of natural philosophy to appear in German, established him as an important figure in the transmission of early scientific literature into the vernacular and an influential source in the development of scientific terminology in German. Also an observer of comets, Megenberg was a prominent scholar in German lands of the mid-14th century. He was one of the major figures at Saint Stephan's School, the predecessor to the University of Vienna, and thus he was a forerunner of such later astronomers as **Georg Peurbach** and **Johann Müller** (Regiomontanus).

Von Megenberg's exact birthplace is unknown, though he spent some of his early years in Erfurt before studying at the University of Paris, where he received his Master of Arts in 1334. At Paris he would undoubtedly have studied and then probably taught (as a lecturer in the Cistercian College of Saint Bernard) Sacrobosco's *Sphere*. While at Paris Megenberg observed the comet of 1337 (C/1337 M1), which he described briefly in his *Buch der Natur*. Megenberg is known to have been active in administration as Procurator of the English Nation, and twice a delegate to the Papal Curia at Avignon. He was listed in the Faculty of Arts at Paris until 1342, when Megenberg moved to Vienna as rector of Saint Stephan's School, where he appears to have introduced astronomy as part of the curriculum. In 1348 Megenberg took the post of Canon at the Cathedral of Regensburg, where he remained for the rest of his life.

Arnold summarizes the known biographical evidence for Megenberg's life and career. He goes on to discuss and analyze Megenberg's German *Sphaera* and also judges him the author, identified in the manuscript as Chunradus de Monte Puellarum, of a Latin commentary on Sacrobosco entitled *Super spera questiones*, although Thorndike (1949) does not draw that connection.

James M. Lattis

Alternate name

Chunradus de Monte Puellarum

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Mellish, John Edward

Born **Madison, Wisconsin, USA, 12 January 1886**
Died **Medford, Oregon, USA, 13 July 1970**

As an amateur astronomer, John Mellish discovered six comets. In his later years as an optical worker, he manufactured many telescopes and optical components for American observatories and astronomers. Raised on a farm near Cottage Grove, Wisconsin, Mellish received a limited education before taking full responsibility for his mother's farming operations. With a strong native curiosity, he invested his spare time in intense investigations of nature including the night sky. After making his own 6-in. Newtonian reflector in 1907, Mellish discovered several comets. He then published a description of the telescope making process in the *Scientific American*. The response to that article, together with his notoriety from the comet discoveries, launched Mellish on a career as an optical worker though he longed for an alternate career in observational astronomy.

Mellish languished in that indeterminate state as farmer, part-time optical worker, and amateur astronomer for 8 years before a major opportunity emerged for him. A shortage of technical staff at Yerkes Observatory prompted director **Edwin Frost** to take a closer look at Mellish on the urging of the aging **Edward Barnard**, who had himself once been an amateur discoverer of comets. When Mellish discovered his third comet in winter 1915, Frost offered him a position as an unpaid observer. A grant to Mellish from the Watson Fund of the National Academy of Sciences paid for a hired hand to work the family farm while Mellish was away. Mellish's arrival at Yerkes Observatory was delayed for over a month by his hasty courtship and marriage to 18-year-old Jessie Ruth Wood of Glencoe, Illinois.

Soon after his arrival at Yerkes, Mellish discovered what he took to be a comet in the rapidly fading dawn twilight. Although the discovery was announced to the international astronomical community by a telegram from Harvard Observatory, the object was soon shown to be a previously catalogued nebula, NGC 2261. Mellish redeemed himself within a few weeks by discovering his fourth comet. After the erroneous comet discovery was announced, **Edwin Hubble**, then a graduate student at Yerkes, studied NGC 2261 photographically. Within a year Hubble announced that, as Mellish had contended, the nebula had apparently changed in appearance. NGC 2261 has since been known as Hubble's variable nebula.

Mellish remained at Yerkes for 15 months, during which he continued to observe regularly with the Yerkes comet seeker as well as other available telescopes. Another early morning session, this time with the 40-in. Clark refractor, resulted in a second controversial Mellish observation. In the post-dawn sky in November 1915 Mellish observed what he described as craters on Mars, although Mars was many weeks beyond opposition and presented a comparatively small image. Mellish was convinced of his observation and discussed the matter with Barnard. Mellish claimed that Barnard showed him his own drawings of Mars. Those drawings displayed circular objects that Mellish took to be craters. However, Barnard's advice was that other astronomers were unlikely to believe such observations and that Mellish would be well advised not to discuss his own observations with others. In his later years, Mellish ignored Barnard's advice and discussed his observations as well as his discussion with Barnard with many other astronomers. The matter was not resolved satisfactorily until the Barnard drawings were discovered in a trunk at Yerkes Observatory in the early 1990s. The three circular markings that Mellish described were actually displayed in Barnard's drawings. However, those markings have now been identified with the Martian volcano *Olympus Mons* and two smaller nearby volcanoes known to exist in the region of Mars that Barnard observed. More recently, careful examination of modern photographs of Mars in connection with an accurate ephemeris of the planet for November 1915 indicates Mellish likely observed the giant impact crater Argyre, the mountains surrounding that crater, Neridium Montes, and the super canyon Valles Marineris, which Mellish described as a crack.

In November 1916, after the Mellish family's first child was born, Mellish accepted an appointment as the director of the Harrold Observatory in Leetonia, Ohio. He discovered his fifth comet in April 1917, but otherwise Mellish's astronomical observing from Leetonia was unproductive. Instead, during this period Mellish faced the reality that he was unlikely to succeed as an observational astronomer and shifted his interest back to optical work. With strong support from Leetonia machine tool manufacturer Elmer A. Harrold (1864–1931), Mellish perfected the telescope mountings for his telescopes. He advertised regularly to the amateur astronomy market and aggressively solicited optical work from professional observatories as well. By the time the Mellish family moved to Illinois from Leetonia in 1923, Mellish had a substantial backlog of orders for telescopes and had become well established as a supplier of optical windows, small lenses, and mirrors for use in professional observatory photometers and spectrographs. Mellish visually discovered a possible sixth comet that later was suggested as being an accidental rediscovery of comet 6P/d'Arrest.

For the remainder of his life, Mellish continued to practice recreational astronomy while maintaining a productive business in optics. His small telescopes, both refracting (up to 10 in. in aperture) and reflecting (many in apertures up to 16 in.), were inexpensive and sustained his business as a continuing workload. In addition, Mellish took on larger mirrors for professional telescopes up to 30 in. in aperture, for example a Pyrex mirror for the University of Illinois. Mellish was asked by **Otto Struve** to produce an unusual set of Schmidt system optics (20-in. × 20-in.) for the McDonald Observatory in 1939. The collapse of his second marriage (also to Jessie) and Struve's impatience with the resultant delays thwarted that effort.

During World War II, Mellish capitalized on skills he learned while making optical windows for observatory instruments by manufacturing rock-salt optics sets for infrared spectrophotometers. He was apparently responsible for 90 percent or more of the optics for these important new instruments for chemical laboratory and refinery process control analyses. He supplied rock-salt optics sets to Shell Development, Pure Oil, Dow Chemical, the University of Michigan, and many other institutions in addition to his regular optics work.

The Mellish family eventually included ten children, but both of Mellish's marriages to Jessie ended in disastrous divorces. The first of these occurred in 1933 in Saint Charles, Illinois, the culmination of a prolonged legal battle as Jessie suffered an extended period of depression. After the first divorce, Mellish moved to Escondido, California, where he reestablished his business with the help of Clarence Lewis Friend (1878–1958). The second divorce occurred in 1939 in Escondido as Jessie's struggle to reestablish herself once again failed. Mellish gave Friend two telescopes and showed him how to search for comets. Friend eventually made independent discoveries of at least four comets.

Mellish was a productive contributor to astronomy for most of his life, with six comet discoveries to his credit and as a telescope maker who supplied inexpensive telescopes for both amateur and professional applications. The International Astronomical Union named a crater on Mars in Mellish's honor.

Thomas R. Williams

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Melotte, Philibert Jacques

Born **Camden Town, (London), England, 29 January 1880**
Died **Abinger, Surrey, England, 20 March 1961**

English astrometrist Philibert Melotte discovered the eighth satellite of Jupiter, Pasiphae, and some southern nebulae carry his name. He was the son of a (Belgian-born, hence the names) lecturer at the Royal Naval College, who enrolled him at the Roan School in Greenwich, where Melotte completed his formal education at age 15. He then joined the staff of the Royal Observatory (Greenwich) as a supernumerary computer, remaining on the staff there for his entire career. At the time, it was the custom of the Royal Observatory to recruit the bulk of its staff members for observation and data reduction from local schools. This was an ideal opportunity for Melotte, as those students who showed particular talent (and were able to pass a set of fairly challenging examinations) were allowed to take up permanent posts when they fell vacant. Melotte was one of these students who, by exceptional talent, rose within the observatory to be a department head.

In his first 10 years at Greenwich Melotte made hundreds of astrometric observations of a wide range of astronomical objects. His most celebrated discovery occurred in 1908 while he was engaged in systematic observations of Jupiter and the known Jovian moons. Melotte had set out to confirm the existence of satellites numbers six and seven (Himalia and Elara), discovered at Lick Observatory (Mount Hamilton, California) by **Charles Perrine** in 1904 and 1905. In the course of these observations he found a "moving object" that, through subsequent investigation, he demonstrated to be a satellite of Jupiter. The discovery of the eighth satellite of Jupiter brought Melotte considerable recognition and the 1909 Royal Astronomical Society's Jackson–Gwilt Medal.

Most of his first decade as an astronomer was, however, spent in measuring the photographic plates for the Greenwich zone of the *Carte du Ciel*. As a result, Melotte was the obvious person to undertake the remeasurement of the astrographic plates taken about 1905 by **John Franklin–Adams** and the compilation of a Royal Astronomical Society edition of the Franklin-Adams star charts (on a much smaller scale of 1° = 20 mm than the *Carte du Ciel* charts). In collaboration with **Sydney Chapman,** Melotte also used these plates for faint star counts, and, still later with **Knut Lundmark,** he examined the obscured regions of the plates. A 1926 catalog of southern nebulae found there includes objects still referred to by their Melotte numbers.

Melotte's early work had been supervised by H. P. Hollis, who was head of the astrographic department, and upon Hollis's retirement in 1920, Melotte succeeded him, though his appointment to appropriate rank was considerably delayed. In 1933, Sir **Harold Spencer Jones** returned from the Cape Observatory to become Astronomer Royal and director at Greenwich. He brought with him some 2,847 photographic plates, taken at a number of observatories during an observing campaign aimed at minor planet (433) Eros with the purpose of improving knowledge of distance scales within the Solar System. Most of the rest of Melotte's career was devoted to measuring and reducing these plates, some of the work being done at Abinger, where the observatory staff was moved at the start of World War II. After the war, Melotte returned to Greenwich, where he remained until retirement in 1948. He had served at the observatory for 53 years.

Melotte was well-known to support the efforts of amateur astronomers, and he willingly provided his expertise in celestial photography to many projects. He was also active in several organizations and served as the secretary of the Royal Astronomical Society's Photographic and Instruments Committee from 1913 to 1950 and secretary to the British Astronomical Association from 1913 to 1921 and again from 1926 to 1930, finally becoming its president in 1944. He was a Freemason of high rank, serving as Treasurer of the Trafalgar Chapter for 30 years, and he was a member of the Royal Naval College Lodge of Mark Master Masons. Melotte was survived by his wife and son.

Scott W. Teare

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Menaechmus

Flourished **(Turkey), *circa* 350 BCE**

Menaechmus, the Greek mathematician who supposedly told Alexander the Great that there is no royal road to geometry, was a pupil of **Eudoxus**, the founder of Greek mathematical astronomy. Menaechmus is said to have added more homocentric spheres to the Eudoxean planetary models, which had already been enriched by **Callippus**. But his greatest achievement was the discovery of the conic sections, which takes pride of place in **Johannes Kepler**'s *Astronomia Nova* (New astronomy) (1609).

Menaechmus defined the conic sections as the intersection of a cone of revolution with a plane perpendicular to one of the cone's generators. He distinguished three kinds, which arise, respectively, by cutting a right-angled, an acute-angled, or an obtuse-angled cone. (**Apollonius** later gave them the names parabola, ellipse, and hyperbola, by which we call them still.) The conic sections occur in Menaechmus' two solutions to the Delian problem of duplicating the cube, which can be readily explained using modern mathematical lore and notation.

Roberto Torretti

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Menelaus of Alexandria

Born **Alexandria, (Egypt), *circa* 70**
Died ***circa* 130**

Menelaus is best known for his development of spherical trigonometry.

Little is known about the life of Menelaus. It appears that he spent his early years in Alexandria, and was probably born there; after that, he seems to have moved to Rome. **Pappus** and **Proclus** both referred to him as Menelaus of Alexandria. **Ptolemy** noted astronomical observations made by Menelaus in Rome on 14 January 98. In addition, **Plutarch** related a conversation about optics involving Menelaus as an adult in Rome around the same time.

Ibn al-Nadim's *Fihrist* (a register of mathematicians, written *circa* 950) mentions six books by Menelaus, some of which were said to have been translated into Arabic at the time. They included *The Book of Spherical Propositions*, *On the Knowledge of the Weights and Distribution of Different Bodies*, three books on the *Elements of Geometry*, and *The Book on the Triangle*. The only book by Menelaus that can be found today is the first in the list above, generally referred to as the *Sphaerica*.

That book documents Menelaus' major contribution to astronomy, which was the development of spherical trigonometry. For example, the first known definition of a spherical triangle appears at the beginning: The Greek term that he used for a spherical triangle, *tripleuron*, was not commonly used by other mathematicians to refer to triangles (although it does occasionally appear in Euclid), and suggests that Menelaus was aware of the originality of his topic. In short, he appears to have been the founder of spherical trigonometry. He is best known today, within that field, for Menelaus' theorem, which has applications to astronomy.

In addition to his theoretical work, Menelaus made many astronomical observations and attempted to organize them and make estimates relating to the movement of the stars. Several 10th-century Arab astronomers (**al-Battani**, **al-Sufi**, and Hajji-Khalifa) allude to a catalog of fixed stars composed by Menelaus; this was apparently not a full catalog, and was largely based on his observations. Based on Menelaus' observations, Ptolemy suggests that Menelaus was able to estimate that the equinox was moving westward at the rate of 1° per 100 years. (A more accurate figure given today is about 1° per 72 years.) Pappus also mentions a treatise by Menelaus on the settings of the signs of the zodiac. (The calculations in this treatise would have involved the use of trigonometry.)

Kenneth Mayers

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Menzel, Donald Howard

Born **Florence, Colorado, USA, 11 April 1901**
Died **Boston, Massachusetts, USA, 14 December 1976**

Donald Menzel combined astronomy and atomic physics to revolutionize our understanding of the physics of the Sun and gaseous nebulae. He founded three observatories and brought the Smithsonian Astrophysical Observatory to Harvard College Observatory to enrich the scientific cultures of both institutions.

Menzel, the son of Charles Theodor and Ina Grace (*née* Zint) Menzel, was raised in Leadville and Denver, Colorado. In Leadville, his father worked as a telegrapher, clerk, and ticket salesman before becoming the proprietor of the city's largest general store. By 1916, the financial success of the store allowed Charles to retire, and the family moved to Denver, where Donald completed high school. As a schoolboy Menzel pursued numerous hobbies, suggested by his insatiable scientific curiosity. These in turn provided an outlet for an almost boundless energy that was to characterize his entire professional life. One such interest, in particular, was to have important consequences later in his life. After his father taught him the Morse code at an early age, Menzel combined this skill and his interest in the emerging field of radio technology to become an amateur radio operator (W1JEX), a hobby he retained for most of his adult life.

Menzel earned BA and MA degrees from the University of Denver, where he carried out observations of eclipsing variable stars under the benign guidance of professor Herbert Alonzo Howe. Through these efforts he established contacts with Princeton University's **Raymond Dugan**, which eventually led to his enrollment for graduate study at Princeton, University in the fall of 1921. Once at Princeton, the new astrophysics being pioneered by **Henry Norris Russell** drew Menzel's attention. During the summers, Russell dispatched Menzel to the Harvard College Observatory, where he identified a few thousand star clusters near the periphery of the Large Magellanic Cloud for **Harlow Shapley**. For his Ph.D., awarded in 1924, Menzel endeavored to establish a stellar temperature scale by using the recent theory of **Alfred Fowler** and **Edward Milne** on application of **Meghnad Saha**'s equation to stellar spectra.

After graduating from Princeton, University Menzel spent a few years on the faculties of the University of Iowa and the Ohio State University before landing a solid appointment at the Lick Observatory. At Lick, he honed his talent in the application of atomic physics to the interpretation of solar and nebular spectra. Menzel's scientific apogee remains his seminal treatise on the solar chromosphere, based on his exhaustive analysis of **William Campbell**'s collection of photographic plates of the so called flash spectrum. This work, published in 1931, stands as a milestone in theoretical astrophysics. It is one of the earliest examples of quantitative astronomical spectroscopy. Menzel's findings revealed that the chromosphere was not in thermodynamic equilibrium, and that helium and hydrogen were the dominant solar chemical components. His work foreshadowed the spectacular conclusion of **Walter Grotrian** and **Bengt Edlén** that the temperature of the solar plasma increased outward into the overlying tenuous solar atmosphere. Menzel also began studies of planetary nebulae at Lick Observatory.

In the fall of 1932, Menzel accepted Shapley's invitation to join the staff of the Harvard Observatory. There, he soon organized the second outstanding example of his facility with astrophysical spectroscopy. With his students and other collaborators, Menzel authored a series of 16 papers on the physics of gaseous nebulae between 1937 and 1945. This systematic study is as valid and valuable today as when it was written. Menzel's collaborators included **James Baker**, **Leo Goldberg**, Malcolm H. Hebb, George H. Shortley, and **Lawrence Aller**. Menzel's other original contributions to the physics of gaseous nebulae included his observation that under some circumstances, light passing through a gas may be amplified through fluorescence, presaging the phenomena now known as lasers and masers. Further, Menzel's observations regarding the dependence of the visual appearance of a gaseous nebula on the three possible combinations of the opacity of the gas to Lyman continuum and Lyman α radiation served as a useful heuristic for several generations of astrophysicists.

Encouraged by the progress made in France by **Bernard Lyot** with his coronagraph, Menzel undertook to develop a similar device for observing the solar corona whenever the Sun was visible. Menzel's coronagraph, which ultimately became much like Lyot's, was installed in an observatory at Climax, Colorado in late 1940 and manned by Harvard graduate student Walter Orr Roberts (1915–1990).

When the United States entered World War II, Menzel suspended his astronomical work to teach cryptography at Radcliffe College, but was soon commissioned as a lieutenant commander in the navy. He coupled his knowledge of radio and solar physics to become an expert on radio and radar transmission. Assigned to the Office of the Chief of Naval Communications, Menzel arranged for frequent advice on solar activity from Roberts at Climax to be transmitted to the Carnegie Foundation's Department of Terrestrial Magnetism, Washington, DC, for use in radio propagation forecasts for the military services. The forecasts were made using methods of analysis Menzel helped to develop. In this effort, Menzel not only demonstrated the critical practical importance of knowledge of the

Sun and solar activity, he also established relationships with key government scientists and administrators that would later prove useful to his observatory construction programs.

Menzel remained at Harvard for the rest of his career, serving as the director from Shapley's retirement in 1952 until 1966, when he was succeeded by his own student Goldberg. In the years immediately following his assumption of responsibility for the observatory, Menzel was faced with some difficult choices. Physical facilities were deteriorating, and the staff was depleted. Menzel was eventually successful in raising funds to modernize the observatory office buildings. To make immediate room for expanding the staff, Menzel severed long-standing relationships with the American Association of Variable Star Observers [AAVSO] and *Sky & Telescope* magazine, which had previously occupied space in the observatory. In addition, he began destruction of the Harvard plate collection, seen by most astronomers as a priceless resource for research. Eventually Menzel abandoned that plan in the face of protests from many astronomers. In addition, **Bart Bok** and a few other key staff members moved on to other observatories. After this difficult period, Menzel was successful in restoring the vigor of both the academic and research programs at Harvard.

In addition to being one of the leading intellectual figures of American astrophysics, Menzel also distinguished himself as a potent scientific entrepreneur in the fine tradition of **George Hale**. During his career, Menzel established three solar observatories: The High Altitude Observatory in Colorado, the Sacramento Peak Observatory in New Mexico, and the Harvard Radio Astronomy Observatory in Texas; he also brought another, the Smithsonian Astrophysical Observatory, to Harvard.

Menzel served as a consultant to various federal agencies, notably the National Bureau of Standards, the Air Force Office of Scientific Research, and the Office of Naval Research, and as a director of the Association of Universities for Research in Astronomy that organized the National Optical Astronomical Observatories. He had a natural talent for popularizing current scientific discoveries and wrote extensively for newspapers, magazines, and even for film. He authored nearly a dozen books ranging from a practical field guide to the stars and planets and a handbook on radio transmission to scholarly monographs on quantum spectroscopy, stellar structure, and mathematical methods in physics.

Curiously, another source of Menzel's fame was his writings on Unidentified Flying Objects [UFOs]. Like Edward U. Condon who looked into this same issue, Menzel concluded that there was no solid evidence to support the claims of those who believed that extraterrestrials were routinely visiting this planet. While completely serious in his belief that there was no evidence supporting the existence of the UFOs, Menzel also exhibited his sense of humor well in this area. Colleagues came to cherish his frequent cartoons of imaginary intruders from other planets.

During the late 1960s Menzel's activity was slowed by a serious circulatory problem. He stepped down from the directorship, but continued his researches as time permitted. Menzel also continued his pilgrimages to solar eclipses often with his wife Florence whom he married in 1926. The final eclipse he observed, on 24 December 1973, was his 16th expedition.

Thomas J. Bogdan

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Mercator, Nicolaus

➔ **Kauffman, Nicolaus**

Merrill, Paul Willard

Born **Minneapolis, Minnesota, USA, 15 August 1887**
Died **Pasadena, California, USA, 19 July 1961**

American stellar spectroscopist Paul Merrill discovered the presence of the short-lived radioactive element technetium in the atmospheres of a few cool, highly evolved stars, proving that these stars must have nuclear reactions going on in their interiors at the present time. He also discovered the diffuse interstellar bands.

Merrill's father was a Congregational minister, and throughout his life the son adhered to this religion. Most of his life was spent in California. Merrill attended Stanford University, earning the AB degree in physical science and mathematics in 1908, and then joined the United States Coast Survey for a short time before entering the University of California in 1909 as assistant and fellow at Lick Observatory, achieving the Ph.D. in 1913. He then taught astronomy at the University of Michigan, 1913–1916.

After leaving the University of Michigan Merrill accepted an appointment with the United States Bureau of Standards from 1916 to 1918. He experimented with treating photographic plates with dicyanin to make them sensitive to red light. Merrill arranged with professor **Edward Pickering**, director of the Harvard College

Observatory, to use Harvard's 24-in. refractor and an objective prism to photograph the spectra of stars on dicyanin-sensitized plates. Whereas ordinary photographic plates reached into the red only slightly beyond the hydrogen Hβ line at 4,861 Å, the sensitized plates reached beyond 8,000 Å. From them he was able to identify several molecules not previously known to occur in stellar spectra.

Finally, in 1919, Merrill went to the Mount Wilson Observatory where he remained not only until his retirement in 1952, but as a volunteer the rest of his life. During his lifetime he published some 260 articles and four books. While at Lick Observatory, Merrill and **Charles Olivier** jointly published two articles on the great January comet C/1910 A1. That same year Merrill published a note on the "Spectrographic Orbit of β Capricorni." Thenceforth the bulk of his publications dealt with stellar spectroscopy and variable stars, in which he did considerable original research. Merrill was also a pioneer in red and infrared photography of stellar objects.

Merrill was particularly interested in wartime advances of photographic techniques that could also be applied to astronomical work. In a 1920 article, "Progress in Photography Resulting from the War," he wrote that the government, which usually considered scientific work an unnecessary luxury, "under the stress of a great emergency acknowledged its value and supplied funds as never before." As a result, certain aspects of research were pursued with unprecedented vigor during the war. Photographs of the ground taken from aircraft had been seriously handicapped by the fact that blue light is scattered in the atmosphere, resulting in blurred photographs on blue-sensitive plates. Red wavelengths, on the other hand, are less affected by scattering. Hence Merrill's experiments with dicyanin-sensitized plates were extended for military purposes. During World War I he designed special airborne cameras and took numerous airplane flights from Langley Field to test his equipment.

At Mount Wilson Observatory Merrill's primary topics of investigation were stellar spectroscopy, infrared photometry, stars with emission lines, and variable stars, especially the spectra of long-period variables. For many years, he edited the publications of the Mount Wilson Observatory written by his colleagues as well as publishing his own work.

Besides his many research papers Merrill published four treatises. The first, in 1938, *The Nature of Variable Stars*, was intended primarily for amateurs and laymen interested in astronomy. In the preface Merrill expressed that his purpose was not only to outline current knowledge of variable stars, but also to clarify for the non-technical reader the general nature of modern astrophysics.

Merrill's second book, *The Spectra of Long Period Variable Stars* (1940), is a scholarly text giving the history of the interpretation of stellar spectra, work to which he contributed extensively. His third book, *Lines of the Chemical Elements in Astronomical Spectra* (1956), not only identified all the elements found in stellar spectra but included over 1,060 references to their discovery and identification. Merrill's final book, *Space Chemistry* was published in 1963, nearly 2 years after his death.

Among Merrill's achievements are his identification of zirconium in S-type stars as well as technetium. He was also the first to suggest that red stars form three distinct branches of the giant red stars. Progressing toward the red side of the HR giant diagram from spectral classes G or K, the most prevalent red stars are class M, showing titanium oxide in their spectra; another branch consists of R and N carbon stars; and finally the S types show zirconium oxide. The variable stars with these spectral classes also show hydrogen lines in emission. Merrill found that 88% of the long-period variables showed M-type spectra, 5% N type, 5% S type, and 2% K or R types, and clarified that the differences in spectral appearance derive from (1) temperature, (2) the ratio of carbon to oxygen, and (3) the ratio of elements around zirconium to those around titanium in the periodic table. The latter two differences are a result of nuclear reactions in the stars themselves and mixing of the products to the surfaces. Other Merrill contributions include (1) the determination of the absolute brightness of the long-period variables with **Ralph Wilson**, using the method of statistical parallax; (2) classification of stars with extended atmospheres with **Roscoe Sanford**; (3) demonstration of turbulence in interstellar gas with **Olin Wilson**; and (4) probably most importantly, the recognition that certain diffuse features, commonly found in stellar spectra (especially those centered around 4430 Å), are actually produced in the interstellar medium. Most of these features probably arise from absorptions by carbon–hydrogen bonds, but the precise substances involved are not yet certain.

Merrill received many honors during his career. He was a member of the National Academy of Sciences and received its Draper Medal in 1945. In the American Astronomical Society [AAS] he served as councilor (1931–1934), vice president (1947–1950), and president (1956–1958), and was the AAS Russell Lecturer in 1955. Merrill was elected to the Council of the Division of Physical Sciences of the National Research Council for 1941–1944, and to the Council of the Astronomical Society of the Pacific, whose Bruce Medal was conferred upon him in 1946. He was a fellow of the American Philosophical Society. Additionally he was a member of the American Association for the Advancement of Science [AAAS], and of the honorary societies, Phi Beta Kappa and Sigma Xi. In 1922 Merrill was elected a fellow, and in 1948 associate member of the Royal Astronomical Society.

In 1913 Merrill had married a school classmate, Ruth Currier. She and their son, Donald, survived him.

Dorrit Hoffleit

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Mersenne, Marin

Born **Oizé, (Sarthe), France, 8 September 1588**
Died **Paris, France, 1 September 1648**

An avid astronomical correspondent, Marin Mersenne provided vital communication links between practicing scientists of his era. He made important contributions in time keeping, experimental practice, and the philosophical approach to science by religion, the latter at some personal risk. Merseene was born into a family of laborers. He spent 5 years at the Jesuit collège at La Flèche beginning in 1604, followed by 2 years of theology at the Sorbonne University in Paris. In 1611 he joined the Franciscan Order of Minims, so named because they considered themselves the least of all the religious orders. Mersenne became a priest in Paris in 1612, and from 1614 to 1619 he taught philosophy at the convent at Nevers. In 1619 Mersenne moved to the Minim convent de l'Annonciade near the Place Royal (now Place de Vosges). Other than for a few short trips, he remained there until his death.

Mersenne's greatest contribution was his continual correspondence and meetings with scientific leaders, developing an informal network for disseminating information well before the inception of scientific journals. It was said "to inform Mersenne of a discovery meant publishing it throughout the whole of Europe." After Mersenne's death, letters from nearly 100 correspondents were found in his cell. Those who visited or corresponded with Mersenne included **René Descartes**, Gérard Desargues, Pierre Fermat, Thomas Hobbes, **Christiaan Huygens**, John Pell, **Galileo Galilei**, Blaise Pascal, and **Nicholas Torricelli**.

Mersenne viewed the question of Earth's motion as undecided and encouraged the search for more scientific evidence to settle the issue, yet he defended Galilei and published his work in French (*Les Méchanique de Galilée* 1634, as well parts of Galilei's *Dialogo* and *Discorsi*). Mersenne felt the church should censor some opinions, but urged moderation because he believed that "true philosophy never conflicts with the belief of the church." Mersenne was a careful experimenter who insisted on precision and repetition. "One should not rely too much only on reasoning," Mersenne wrote, as he questioned whether or not Galilei actually carried out some of the experiments on acceleration down a plane that Galilei described.

In 1636 Mersenne proposed a design for a reflecting telescope using a concave paraboloidal primary and a convex paraboloidal secondary arranged so that their focal points coincide. The electro-optics branch at the National Aeronautics and Space Administration's Marshall Space Flight Center uses an off-axis Mersenne telescope in a lidar (light detection and ranging) system.

Mersenne was the first to discover that the frequency of a pendulum is inversely proportional to the square root of its length, and it was Mersenne who proposed the use of a pendulum as a timing device to Huygens, inspiring him to invent the pendulum clock.

In other fields, Mersenne is often credited with developing the system of tuning musical instruments called equal temperament, and he experimentally developed three important principles in the acoustics of stringed instruments. Mersenne also published results on the cycloid, reported on the chemistry of tin, discussed a "sensitive plant" from the West Indies, and sought a perfect language that was natural and universal for communication of scientific ideas.

Chris K. Caldwell

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Messier, Charles

Born **Badonviller, (Meurthe-et-Moselle), France, 26 June 1730**
Died **Paris, France, 12 April 1817**

Charles Messier, the first astronomer to search systematically for comets, published memoirs of his astronomical observations on solar-system phenomena, including his observations of 44 comets. He made independent discoveries of 20 comets. However, Messier is best known today for his catalog of the 103 brightest nebulous objects in the skies visible from the Northern Hemisphere.

Messier was the tenth of twelve children of Nicolas Messier, a catchpole, and Françoise B. Grandblaise. Six of his brothers and sisters died at young age; his father died in 1741. Messier was educated by his older brother, Hyacinthe, who was working in the administration of the princes of Salm, reigning in Badonviller at that time. When the princes gave up Badonviller in 1751, Hyacinthe left for Senones, and Charles Messier went to Paris. Messier's interest in astronomy originated when he saw the great six-tailed comet (C/1743 X1) independently discovered by **Jean-Philippe Loys de Chéseaux** and Dirk Klinkenberg (Haarlem, the Netherlands). The annular eclipse of 25 July 1748 was also visible from his hometown.

In 1751 in Paris, the astronomer of the navy **Joseph Delisle** employed Messier, because of his fine handwriting, as a clerk. In addition to a small salary, Delisle provided a room for Messier at the Hôtel de Cluny. Delisle's secretary introduced Messier to the astronomical observatory on Hôtel de Cluny and instructed him to keep careful records of his observations. Messier's first documented observation was the Mercury transit of 6 May 1753. Delisle convinced Messier of the necessity of measuring exact positions for all observations – one of the most important preliminaries to his success as an observational astronomer. In 1754, Messier was regularly employed as a depot clerk of the navy.

In 1757 Delisle directed Messier to search for a comet expected to return in 1758. At that time, the return was no more than a prediction by **Edmond Halley**. Because of an error in Delisle's calculations, Messier looked at wrong positions for months. However, in August 1758, he discovered another comet (which had been discovered previously) and a comet-like patch in Taurus. The latter was not moving and was thus not a comet, but a nebula. Now known as the Crab Nebula, the remnant of the 1054 supernova, it became the first entry in Messier's catalog of such comet-like objects. Messier later reported that it was this pair of discoveries that prompted him to continue looking for comets with telescopes and to compile his catalog of nebulous objects that might be mistaken for comets.

Messier finally succeeded in finding comet 1P/Halley in January 1759, 4 weeks after its recovery by **Johann Palitzsch**. The secretive Delisle witheld the announcement of Messier's discovery until April; other astronomers were then skeptical about the late announcement. In 1760, Messier made his first independent comet discovery. He continued searching for and observing comets with telescopes over the decades, making original discoveries for a total of 13, and independently codiscovering another seven up to 1801.

Though Messier discovered more nebulous objects that could be mistaken for comets during his comet searching, he had little interest in these objects *per se*. In 1764, he undertook a serious scan of the skies, and compared his results to all the catalogs and lists available to him (those of Halley, **William Derham**, **Johannes Hevel**, **Nicolas de La Caille**, **Giovanni Maraldi** and **Guillaume le Gentil de la Galazière**) to compile a catalog of all such comet-like objects.

His catalog had grown to 45 objects when Messier decided to publish it in 1769, in the *Memoirs* of the French academy for 1771.

When Delisle retired in 1765, Messier continued to work at the Hôtel de Cluny, but it was not until 1771 that he was reclassified as astronomer of the navy. Because of his numerous comet discoveries, his fame spread. French King Louis XV nicknamed Messier "The Comet Ferret." He was elected to most scientific academies existing at that time, including the Academy of Haarlem (1764), the Royal Society (London, 1764), the Royal Academy of Sweden (1769), the Royal Academy of Prussia (1769), and the academies of Belgium (1772), Hungary (1772), and of Russia (1777). Although a proposal to elect Messier to the Royal Academy of Sciences in Paris had failed in 1763, on 30 June 1770 he was finally honored in his own city. He became good friends with the astronomer/mathematician **Jean Bochart de Saron**, who evaluated Messier's observations and calculated orbits of his comets to help him find them after perihelion.

At the age of 40, Messier married Marie-Françoise de Vermauchampt, who was 37; they had known each other as astronomical observers for about 15 years. On 15 March 1772, Madame Messier gave birth to a son, who was christened Antoine-Charles. Tragically, both the mother and the infant died within 11 days.

Messier started a most fruitful cooperation with a younger astronomer, **Pierre Méchain**, whom he met in 1774. Together, they produced a second version of Messier's catalog in 1780; they added 23 new objects to bring the catalogue of nebulae and star clusters to 68 entries. Their vigorous effort increased the number of entries to 103 in the third version published in 1781. Both the second and third editions of the catalog were published in the French almanac, the *Connaissance des Temps*. Twentieth-century astronomers added seven more objects from Messier's and Méchain's notes, expanding their catalog to 110 objects. Messier himself originally discovered 44 and independently codiscovered about 20 of them: 11 nebulae, 27 open star clusters, 29 globular star clusters, 44 galaxies, and 3 other objects (star cloud M24, double star M40, and M73, an asterism of 4 stars).

On 6 November 1781, Messier was severely injured when he fell about 25 ft. into an ice cellar while walking in a park with Bochart de Saron. It took Messier more than a year to recover. In November 1782, Messier resumed his assiduous observing activities, again concentrating on comets.

As a result of the French Revolution, the Royal Academy of Sciences was closed in 1793. Among the many victims of the revolution was Messier's friend Bochart de Saron, who was guillotined on 20 April 1794. In 1795, Messier entered the Bureau of Longitudes and the new National Institute of Sciences and Arts, which succeeded the academy. In 1806, he received the Cross of the Legion of Honor from Napoleon Bonaparte. Suffering from failing eyesight, Messier made his last comet observation of the great comet C/1807 R1. In 1815, Messier suffered a stroke that left him partially paralyzed. He passed away in his home in Hôtel de Cluny.

A lunar crater and the minor planet (7359) are named Messier, in his honor. The 1775 proposition of **Joseph-Jérôme de Lalande** to name a constellation for him, *Custos Messium*, was soon rejected. However, his most obvious honor is certainly the common naming of deep-sky objects for him, with their catalog numbers, for example Messier 42 or M42 for the Orion Nebula, and M31 for the Andromeda Galaxy.

Hartmut Frommert

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Metcalf, Joel Hastings

Born **Meadville, Pennsylvania, USA, 4 January 1866**
Died **Portland, Maine, USA, 23 February 1925**

Joel Metcalf enjoyed three simultaneous and challenging careers: a pastoral career of considerable intensity; a career as a very successful amateur astronomer with the discoveries of 41 asteroids, 5 comets, and at least 10 variable stars to his credit; and a third career as an outstanding optical designer and craftsman, with four important instruments to his credit.

Metcalf was the son of Lewis Herbert and Anna (*née* Hicks) Metcalf. Lewis, a Civil War veteran, lost a leg at the first battle of Bull Run and was held at Libby Prison, Richmond, Virginia. After marrying and settling in Meadville, Lewis served as a newspaper editor and as county treasurer.

At about age 13, Joel Metcalf read **Richard Proctor**'s book, *Other Worlds Than Ours*, which triggered his lifelong interest in astronomy, an interest that was further stimulated by the close conjunctions of Jupiter and Mars in 1879 and 1881. Metcalf acquired his first telescope, a 2-in. French spyglass, in 1882. This was replaced in a few years by a 3.6-in. Fitz refractor. Metcalf graduated from Meadville Theological Seminary in 1890, continued his education for a year at Harvard Divinity School, and completed a Ph.D. at Allegheny College, Meadville, in 1892. He married Elizabeth S. Lockman, of Cambridge, Massachusetts, in September 1891. They had a son and a daughter.

Metcalf was ordained as a Unitarian minister in 1890. After organizing a church in Roslindale, Massachusetts, Metcalf accepted his first formal pastorate in Burlington, Vermont in 1893. That same year, Metcalf began to perfect his techniques for designing and polishing lenses.

In 1901, Metcalf acquired a 7-in. Alvan Clark & Sons equatorial from the estate of Elisha Arnold, a wealthy amateur astronomer of Keesville, New York. The telescope and its heavy mounting, a one-ton granite pier, and the dome were all transported across the frozen Lake Champlain, New York, in February. The dome and granite pier were nearly lost when the ice cracked and the horses bolted.

The load straddled the crack perilously, supported only by the edges of the dome, before neighbors helped Metcalf complete the transportation. After the observatory was reassembled in Burlington, Metcalf apparently limited himself to recreational observing; he published no formal scientific papers during this 10-year period of his career. The observatory was eventually donated to the University of Vermont.

After a decade of intense community service in Burlington, and exhausted to the point of a nervous breakdown, Metcalf took a leave of absence to spend a year at Oxford University in England. There, he attended an average of 24 lectures weekly on philosophy and religion. Oxford's Radcliffe Observatory director **Herbert Turner** became aware of Metcalf's intense interest in astronomy, and gave him keys to the observatory. Metcalf observed furiously in addition to his vigorous classroom participation. He published one project in the *Monthly Notices of the Royal Astronomical Society*, the astrometric positions and magnitudes of 90 stars in Cygnus. Although stressed by this dual occupation, it provided welcome relief for Metcalf; he returned to the United States exhausted but mentally refreshed.

After his return from England, Metcalf served at the First Congregational Church in Taunton, Massachusetts from 1904 to 1910. As a minister, he was very active in the social issues of the time, child labor, low wages, and social injustice, and called for slum elimination. Metcalf belonged to the Taunton Science Club, was elected president of the Ministerial Association, and in April of 1906 was elected to the Executive Committee of the Channing Conference of Unitarian churches in Rhode Island, Southern Massachusetts, and Eastern Connecticut.

By late 1905 Metcalf had reestablished himself in astronomy with a new roll-off roof observatory. In addition, he completed a 12-in. photographic telescope with which he could record a field of stars over 4° in diameter on an 8-in.-by-10-in. photographic plate. It was in Taunton, using the 12-in. camera, that Metcalf's career as a discoverer of asteroids, comets, and variable stars ignited. Following a suggestion by **Solon Bailey**, Metcalf developed a new photographic asteroid search procedure. In a reversal of the normal process, Metcalf guided his telescope so it would track the retrograde motion of an asteroid as it drifted slowly against the background of stars. The consequence of this change was that stars appeared on photographic plates as lines, but any asteroid in the field appeared as a single spot. The asteroid was not only easy to identify, but much fainter asteroids were detected because their light was all concentrated in one spot. Metcalf took two exposures one half hour apart, shifting the plate slightly between them, to avoid misidentification of plate flaws. Within 3 months Metcalf discovered three new asteroids, in late 1905 and early 1906. He described his new procedure for the information of other astronomers in the *Astrophysical Journal*. In a second *Astrophysical Journal* paper he demonstrated how the procedure could be used to study short-term light variations in asteroids. Metcalf discovered 31 asteroids from Taunton using this procedure. He also discovered six variable stars photographically, AK Her, RW Leo, SS Tau, UU Tau, UV Tau, and NSV04158 Cnc. On 15 December 1906, while searching for asteroids photographically, Metcalf discovered the short-period comet now known as 97 P/Metcalf-Brewington.

Metcalf accepted a call to a new pastoral assignment at the Unitarian Society in Winchester, Massachusetts in 1910. He made his 32nd asteroid discovery, his first from Winchester, in November 1911. In the next 3 years Metcalf discovered nine more asteroids bringing his total to 41. During his stay in Winchester, he also discovered one more variable star, NSV 04891 Leo.

Metcalf's work in optics was conducted mainly as recreation during Unitarian summer camps at South Hero, Vermont. In addition to the 12-in. photographic doublet, he developed a 7-in. folded *f*/10 refractor for use as a comet seeker. Sweeping the sky from a hill near their summer cottage with this telescope in August 1910, he discovered comet C/1910 P1 (Metcalf). His third comet, C/1913 R1 (Metcalf), was also discovered from South Hero. Other optical work computed and polished by Metcalf at South Hero included a 10-in. triplet for photographic patrol work at Harvard's Oak Ridge Observatory. The 10-in. triplet went into service at the Boyden Observatory, University of the Orange Free State, Bloemfontein, South Africa. The 12-in. doublet used for so many asteroid, comet, and variable star discoveries in Taunton, and Winchester, is now located at Oak Ridge Observatory, as is a 16-in. *f*/5.25 photographic doublet that Metcalf designed and polished under contract to Harvard.

When the United States entered World War I, Metcalf volunteered to serve the troops through the Young Men's Christian Association. Assigned to the front lines with the 3rd division, 7th infantry, he saw action at Château Thierry and the battle of the Marne, delivering letters, cigarettes, and candy to the troops, and even carrying wounded soldiers and/or their equipment during frequent 25-mile marches. He received a citation for bravery in action, and recuperated in Paris after experiencing shell shock and being exposed to mustard gas. After returning to the United States in 1919, Metcalf volunteered to go with the Unitarian Church to Transylvania (Hungary) to help with the reconstruction of 100 churches in that country.

Metcalf's last pastoral assignment was in Portland, Maine, where he served until his death. While vacationing in South Hero, he discovered two more comets, including 23P/1919 Q1 (Brorsen–Metcalf) and C/1919 Q2 (Metcalf). This was the second recorded apparition of comet 23P, a comet with an orbital period around 72 years. Metcalf also made an independent rediscovery of comet 22P/Kopff in 1919, and discovered two more variable stars, SV Hya and WZ Oph. Thus, although the rigors of Metcalf's war service had taken a severe toll on him, he was still making contributions to astronomy. At the time of his death, Metcalf was making a 13-in. photographic triplet lens of his own design. The triplet lens was later completed by C. A. Robert Lundin of Alvan Clark & Sons and used in the discovery of the planet Pluto by **Clyde Tombaugh** at Lowell Observatory.

A further appreciation of Metcalf's importance in astronomy may be gained in several quite different ways. Metcalf was chair of the Visiting Committee for Harvard College Observatory and a member of the Visiting Committee for the Ladd Observatory at Brown University, serving as chair of a search committee when Brown University needed a new observatory director. **Edward Pickering** nominated Metcalf to serve on both the Comet and Asteroid Committee of the American Astronomical Society.

Metcalf died of an aneurysm. About 900 persons attended his funeral in Portland including several justices of the Supreme Court.

Richard R. Didick

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Metochites [Metoxites], Theodore [Theodoros, Theoleptos]

Born **Nicaea, (Iznik, Turkey), 1260/1261**
Died **Constantinople, (Istanbul, Turkey), 1332**

Son of George Metochites, a cleric of the Eastern Orthodox Church during the imperium of Emperor Michael VIII Paleologos, Theodore Metochites grew up in the cultural center of Constantinople. However, because his father George favored union with the Latin Church, the family was exiled. Theodore, nevertheless, received a good education and completed his *enkyklios paideia* by the time he was 20. Favored by Emperor Andronikos II, he became a close collaborator and counselor. In this capacity he made several important diplomatic missions to Cyprus, Serbia, and Thessaloniki, among others, and was appointed to several successively more important public offices. In 1304, Metochites was appointed to the highest position of the Byzantine administration, *megas logothetes*, or Grand Deputy, with duties equivalent to chancellor or prime minister, which he held until 1321.

Metochites's career ended when the emperor was deposed, and he was exiled by the new Emperor Andronikos III Paleologos. He died, as the monk Theoleptos, in 1332 at the Chora monastery in Constantinople to which he had donated his extensive library, and whose restoration work he had personally supported. Metochites's mosaic portrait in the monastery where he offers the Church of Chora to the enthroned Christ commemorates his extensive gifts to the institution.

Metochites was an exceptionally prolific writer and scholar, leaving behind works of rhetoric (royal eulogies and discourses), 20 poems, a literary testament in verse, a collection of philosophical texts, and two works on astronomy. His collection of texts, *Hypomnematismoi kai semeoses gnomikai* (Annotations and gnomic notes or Personal comments and annotations), an astonishing collection of essays and texts on history, literature, and thinking, includes material on over 70 Greek authors. It contains the most extensive commentary on Aristotelian philosophy of the late Byzantine period. Metochites's commentaries on the *Dialogues of Plato* had an important influence on the Platonic renaissance of the 15th century.

Metochites's work associated with astronomy includes his paraphrases of **Aristotle**'s works on natural philosophy and his comprehensive introduction to Ptolemaic astronomy. His *Stoicheiosis Astronomike* (Elements of astronomy) revived Ptolemaic studies in Byzantium and gives evidence of the significance of contacts with Persian and Arabic science in astronomy as practiced in the period of the early Paleologai. In this work, Metochites described earlier astronomical studies and made a clear argument for the importance of astronomy over the other branches of mathematics. He clearly distinguished between astronomy and the then popular apotelesmatics (astrology), which he condemned. In his *Semeoses gnomikai* (Annotations), Metochites provided an important critique of Aristotle.

Katherine Haramundanis

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Meton

Flourished **Athens, (Greece), *circa* 432 BCE**

An early careful and quantitative observer, Meton is known for his calendrical discoveries, some of which are still in use today.

Meton was the son of Pausanias, but little is known of his life apart from a few probably apocryphal stories, such as the tale, found in **Plutarch**, that he simulated madness to avoid military service. Meton was a contemporary of the famous Greek playwright Aristophanes, who characterized him in his still popular comedy *The Birds*, as a ridiculous geometer. The picture of Meton given here is, of course, a caricature, but it indicates that he was well known to contemporary Athenians, as he himself avers in the play, and it probably contains more than a grain of truth. He is shown wearing soft boots, typical of women and effeminates, and he makes a show of publicly carrying out his researches.

Like most other ancient Greek astronomers, however, Meton is known essentially for his contributions to science. He may well be the first astronomer who moved away from an approach to astronomy tied up with magic and came to conclusions based on serious, scientific investigations. He is certainly the first personality on whom those pillars of ancient astronomy, **Hipparchus** and **Ptolemy**, relied as a collector of reliable and usable data.

Meton, probably along with others (notably **Euctemon**), carried out careful observations to detect the solstices, by determining when the shadow cast by a gnomon was at its maximum and minimum. He observed that 235 lunations, or synodic months, amount approximately to 6,939 days and 16.5 hours, while 19 solar years amount to 6,939 days and 14.5 hours – a difference of only two hours. Now 19 years of lunar months amount to 228; by intercalating 235–228 = 7 months over the course of the 19-year cycle, it is possible to synchronize lunar months and solar years.

This observation has no relevance to the Gregorian calendar (which is based on the Sun) or to the Muslim calendar (which is based on the Moon, and hence runs perpetually about 11 days shorter than the solar year). Meton's observation has, however, had continuing relevance for the Jewish calendar, which determines how all Jewish festivals fall. These are observed to this day by Jews throughout the world.

The ancient Hebrew calendar was basically lunar, but the festivals such as Passover had to fall at the appropriate season of the year. Originally this calendar was *ad hoc*. When the New Moon was sighted, the Jerusalem Sanhedrin declared the new month, which might occur after 29 or 30 days (since the mean synodic month is slightly over 29.5 days long), and the message was relayed by beacons on high places to persons living at a distance. When the spring month in which Passover would be celebrated was approaching, yet there were no signs of spring, the authorities would announce the intercalation of a full month, in order to "catch up" with the Sun. Such a calendar is self-correcting, since a dubious call in respect of the sighting of the Moon or the intercalation of the month, would be corrected next time around. On account of political changes, such a system gradually became unworkable, and around the 7th century Meton's cycle was used to substitute a perpetual calculated calendar, still in use today. In it, some slight modifications known as "postponements" were introduced, in order to avoid the coincidence of certain religious celebrations on or near the Sabbath, with attendant religious problems. This calendar was more accurate than the Julian calendar, despite its relatively large swings, but will ultimately require correction (to allow for the slight error in the ancient calculation of the mean lunation period).

The Metonic cycle also determines the Christian festival of Easter. Easter was originally fully dependent on the Jewish Passover, but, beginning with the Council of Nicaea in 325, the Church attempted to fix an independent, agreed date. In the west this was eventually settled on as the first Sunday after the paschal moon occurring on or after the Vernal Equinox, reckoned as 21 March. But the determination of the paschal moon is based on Meton's cycle and does not necessarily correspond to the astronomical Full Moon, any more than the beginning of a Jewish month necessarily corresponds with the New Moon.

The Metonic cycle has its place in the Julian Period proposed in 1583 by Joseph Justus Scaliger, and named by him for his father Julius. This consists of numbered days in a period of 19 × 28 × 15 = 7,980 years, beginning on 1 January 4713 BCE. The figure was arrived at by multiplying together the numbers of years in the Metonic cycle, the solar cycle of the Julian calendar, and the ancient Roman cycle of indiction. The starting point was the nearest past year in which the cycles began together. Julian dates are still in use by astronomers.

Another place where the Metonic cycle figures is in the calendrical ciphers known as clog almanacs, found on boards or sticks, used in western Europe for hundreds of years until the 17th century. These present the so called golden number, which gives the position of a particular year within the Metonic cycle. They were first noticed in England by Richard Verstegan in his book *A Restitution of decayed intelligence* (London, 1634) p. 58:

> They used to engrave upon certaine squared sticks about a foot in length the courses of the Moones of the whole yeere, whereby they could al waies certainely tell when the new Moones, full Moones, and changes should happen as also their festival daies.

Alan D. Corré

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Metrodorus of Chios

Flourished **Chios (Khíos, Greece), *circa* 325 BCE**

Metrodorus of Chios formulated the first theory of the origin of the Universe and made several early contributions to astronomy and cosmology. He is often confused with Metrodorus of Lampsacus, but the two have no relation to each other. Metrodorus of Chios (hereafter referred to as Metrodorus) was most likely born in the fourth century BCE, though Smith suggests the date 500 BCE is more probable. However, Freeman (1966) indicates that his father was put to death during the reign of Antigonus Gonatas between 323 and 301 BCE, putting his (Metrodorus' father's) birth date between 400 and 380 BCE. This means Metrodorus could not have been born earlier than 380 BCE.

Metrodorus was the son of Theocritus, who was a well-known statesman in Chios. Theocritus was, oddly enough, the student of yet another Metrodorus, who some have suggested is the younger Metrodorus' namesake. Theocritus was also a leader of an anti-Macedonian democratic party in Chios, but these political interests do not seem to have been inherited by his son, who was largely interested in the physical sciences and epistemology. Metrodorus was thought to have studied under **Democritus**, though some scholars have argued that Metrodorus simply learned the teachings of Democritus from Nessas. This latter point makes sense in light of the likely dates of his life, for Democritus died in 359 BCE and Metrodorus most likely was born well after 380 BCE, making him too young. Once Metrodorus had established himself as a philosopher, his pupils included Diogenes of Smyrna, who later taught Anaxarchus.

Metrodorus' views on the physical sciences are described in his book *On Nature*. Metrodorus espoused the view that the stars, like the Moon, were lit up by the Sun, and that the Milky Way marked the line of passage of the Sun. Meteorites were sparks caused by the collision of clouds drawn up by the Sun. The Sun's heat also apparently caused the winds to form. This latter fact is due to his view that the Sun was a "sediment" of the air and was constantly quenched and ignited. This occurs when air condenses, forms a cloud (of water), and descends on the Sun, which puts out the fire. However, it is reignited when the water dissipates. Metrodorus extended this concept to describe some processes of the early Universe. He said that this process of quenching and reigniting continued until the fire of the Sun dominated the water vapor around it. The stars then formed from portions of this water vapor. (Basically they were ignited clouds.) He also extended the quenching and igniting aspect to explain night and day, as well as eclipses. This concept is fascinating, as it is one of the earliest scientific (albeit completely incorrect) explanations of the formation of the Universe.

Meotrodorus' views on cosmology also contained another progressive viewpoint. It was his opinion that the world was only one of many, since "it is as unlikely that a single world should arise in the infinite as that a single ear of corn should grow on a large plain" (Guthrie, 1965, 405). In terms of the ordering of the cosmos, Metrodorus held that the Sun was the highest object in the sky, with the Moon next and beneath them the planets and stars. Metrodorus also contributed several noteworthy arithmetical puzzles, including some that dealt directly with astronomy.

Ian T. Durham

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——— (1925). *History of Mathematics.* Vol. 2. Boston: Ginn and Co. (Reprint: New York: Dover, 1958.)

Michell, John

Born **Nottinghamshire, England, 1724**
Died **Thornhill, (West Yorkshire), England, 21 April 1793**

Reverend John Michell demonstrated the existence of binary stars and physical star clusters, predicted the existence of black holes, and made the first realistic estimate of the distance to a star, all major intellectual achievements for an 18th-century English scientist – clergyman.

Michell is thought to have been born in Nottinghamshire, perhaps on Christmas Day 1724, but that is uncertain. There are no portraits available, and only a brief description of him as "a little short man, of a black complexion, and fat" exists in a contemporary diary. It is known that he married a Sarah Williamson in 1764 but that she died the next year.

In 1742 Michell became a student at Queens' College, Cambridge University, from which he received his MA (1752) and BD (1761) degrees. During this time he held the first of several rectorships at churches in the region.

In 1767 Michell published a paper on double stars and clusters, arguing that they were far more common than would be the case if stars were randomly scattered over the celestial sphere. For example, he estimated that there was only about one chance in 496,000 that random placement would result in a cluster like the well-known Pleiades. Consequently, he argued that most close pairs of stars must be physical binary star systems and most clusters must be physically close groups of stars, probably held together by the gravitational force. This was apparently the first use of statistical arguments in astronomy, and the result was confirmed when **William Herschel** measured the motion of the stars in a few binary pairs around each other.

Michell was also a telescope builder; he built his own reflector with a 30-in.-diameter primary mirror and a focal length of 10 ft. After his death, this telescope was purchased by Herschel, who built a newer but similar reflector.

In May 1783 Michell wrote a fascinating letter to **Henry Cavendish** (1731–1810), which Cavendish read before the Royal Society on 27 November 1783 and had published in the *Philosophical Transactions*, 1784. Starting from **Isaac Newton**'s corpuscular theory of light, published in his *Opticks*, Michell pointed out that light particles leaving an astronomical object such as a star would slow down like any other objects in a gravitational field, and that this decrease in speed might be used to provide information about the mass and distance of stars. For example, the images through a prism of different stars would be offset differently depending on the speeds of their light, and from this one could recognize differences in mass.

Michell also pointed out that if a star was massive enough, its escape speed might exceed the speed of light from the star, so that light could not escape, rendering the star invisible – the first known description of what we now call a black hole. He also tried to determine the mass of such a star on the assumption that it had the same density as the Sun, and estimated that it would have 497 times the diameter of the Sun, stating that "a body falling from an infinite height towards it, would have acquired at its surface a greater velocity than that of light, and consequently, supposing light to be attracted by the same force in proportion to its *vis inertiae*, with other bodies, all light emitted from such a body would be made to return towards it, by its own proper gravity." Such a classical Newtonian black hole star would be incredibly more massive than the Sun, of course, far more than is required by the modern theory of black holes. However, his calculation of the mass-to-radius ratio was correct.

Michell apparently did not think it likely that many such unseen stars would exist, but he pointed out that the presence could be detected by their gravitational influence on nearby objects. For example, a binary system with a black hole would seem to have a star revolving around nothing. Indeed, black holes can be detected in this fashion today.

The following year, 1784, Michell made the first realistic assessment of the distances to the stars. Reasoning by means that are analogous to modern photometric parallaxes, he used the apparent diameter and brightness of Saturn, and its known distance from the Sun, to infer that Vega, with approximately the same brightness as Saturn, must be some 460,000 astronomical units from the Sun. The actual distance is more than four times that much but Michell could not have guessed that Vega is intrinsically much brighter than the Sun. It was over 50 years before **Friedrich Bessel** measured the first stellar parallax to confirm the enormous distances that Michell had been the first to realistically estimate.

In his later years Michell addressed the problem of determining the density of the Earth. Since the radius of the Earth was well known, this was equivalent to determining the mass of the Earth and also the value of *G,* the constant in Newton's law of gravitation. For this purpose Michell devised a truly beautiful experiment to measure the force of gravitation between small lead spheres affixed to the ends of a 6-ft. wooden beam and large lead spheres placed nearby. The beam was to be suspended from a single metal fiber acting as a torsional balance, which Michell invented independently of, and perhaps before, Charles de Coulomb. Measuring the angles of rotation of the fiber with the large sphere first on one side of the beam and then the other, the force between the lead spheres could be compared with the gravitational force of the Earth on the spheres, allowing determination of the density or mass of the Earth.

Michell died before carrying out this experiment, but his apparatus was given to Cavendish, who rebuilt the apparatus and carried out the experiment. This well-known Cavendish experiment (more appropriately, the Michell–Cavendish experiment) produced a value of 5.48 for the specific gravity of the Earth, compared to the modern value of 5.52. Cavendish's 1798 paper on this experiment begins with a long description of Michell's apparatus and experimental design.

In geology, Michell carried out seminal studies of earthquakes, earning him the title "father of seismology." The great Lisbon earthquake of 1755 intrigued Michell, who developed a theory of earthquakes, read to the Royal Society of London in 1760 and published in *Philosophical Transactions*. He suggested that earthquakes were produced when two different layers of rocks rubbed against each other at a particular location many miles beneath the surface of the Earth (now referred to as the epicenter), perhaps caused by steam produced by volcanos. The earthquakes were wave motions of the solid material of the Earth, which traveled from their source to other parts of the Earth. Michell distinguished between two different types of waves of different speeds, which he expected would enable the location of the epicenter to be determined.

While at Cambridge Michell wrote a *Treatise of Artifical Magnets* (1750), describing for the first time in print how to make strong artificial magnets. He also reported experiments that showed the forces between magnets were consistent with an inverse-square law between individual poles of the magnets.

Michell's work on earthquakes and seismology led to his election in 1761 as a fellow of the Royal Society of London, a position he had coveted. It also merited him the Woodwardian Chair of Geology at Cambridge University, which he held from 1762 to 1764. In 1767, apparently in order to earn a better living, Michell became rector of the Church of Saint Michael and All Angels in Thornhill, near Leeds, Yorkshire, England, where he remained the remaining 26 years of his life, and where he was buried.

Laurent Hodges

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Michelson, Albert Abraham

Born **Strenlo (Strzelno, Poland), 19 December 1852**
Died **Pasadena, California, USA, 9 May 1931**

Albert Michelson made the first measurement of a star's diameter and many measurements of the speed of light. His longevity, extraordinary skills of observation, and his enthusiasm for research (which he often expressed as "It is such good fun!") allowed him to make significant other contributions to the fields of optics, astronomy, and the study of light.

Michelson came to the United States as a child in 1855, living with his parents first in New York and then in the western states of Nevada and California. He attended high school in San Francisco, California, where his science teacher encouraged him to continue his formal education after matriculating in 1869. Michelson was able to secure a position at the United States Naval Academy, at Annapolis, Maryland (the first Jew to be admitted) and graduated in 1873. Following this he served as a midshipman in the navy for 2 years and then was appointed to the position of instructor of physics and chemistry at the Naval Academy from 1875 to 1879. While this is an impressive start to his career, it is even more so when it is noted that there were no vacancies at the Naval Academy when Michelson was applying for admission. It was only through the favorable impression made on President U. S. Grant and high-ranking navy officials at the meeting he arranged in Washington, DC, that he was able to secure the appointment.

Michelson married Margaret McLean Heminway in 1877, and they had three children. They eventually divorced, and Michelson later married Edna Stanton in 1899; they had three children. In 1879, Michelson took up a post at the United States Naval Observatory Nautical Almanac Office in Washington to work with **Simon Newcomb**. The following year he received a leave of absence to travel to Europe, where he studied at the Collège de France and the universities of Heidelberg and Berlin. On his return to the United States in 1881 Michelson resigned from the navy.

Michelson received an appointment as professor of physics in the Case School of Applied Science in Cleveland, Ohio, in 1882, which he held until 1889 when he accepted a similar position at Clark University at Worcester, Massachusetts. Michelson was offered the position of professor and head of the Department of Physics at the University of Chicago in 1892, which he accepted, and he remained there for the rest of his career.

Throughout his career, Michelson's research focused on experimental optics, and most of his 78 papers concerned light. Some of his major accomplishments were the measurement of the velocity of light, ruling of diffraction gratings, development of one kind of interferometer, null detection of the Earth's motion through the "ether," development of the echelon spectrometer, measurement of stellar diameters, and an investigation of the metallic colorings in nature. His research influenced other eminent scientists. **Albert Einstein**, for example, probably knew about Michelson's results on the speed of light and its constancy when he formulated his Special Theory of Relativity, in which such constancy was postulated.

Michelson's lifetime of research into the nature of light began as an instructor at the Naval Academy when he was ordered to construct an experiment to measure its velocity. Using what was essentially "home built" equipment, he found he was able to make the measurements. Most surprising was that his measurements proved more accurate than any that had been previously obtained! Michelson continued to work on making more accurate measurements of the velocity of light while he was at the Case School of Applied Science, and in 1883 he reported a value of 299,853±60 km/s.

In 1887 Michelson and **Edward Morley** collaborated in investigating the motion of the Earth through hypothetical ether using the Michelson interferometer. The presence of the ether was expected to produce a 0.4 fringe difference for two heams of light travelling the same distance parallel and perpendicular to the Earth's direction of motion. However, the measured difference was less than 0.01 fringe, or in other words the effect of the ether was not detected.

Also in 1887 Michelson and Morely showed that they were able to accurately define the length of the standard meter using measurements of the wavelength of light. Using the interferometer and the red cadmium light line, they were able to determine that 1,553,163.5 wavelengths of this light made up a meter. Since the wavelength of light remains constant over a wide range of conditions, they proposed that it would be a better way to define the standard length of a meter rather than the then used "metal bar" standard for the meter. The use of light to define the meter was generally adopted in 1960.

In 1882 Michelson published the theory of his "differential-refractometer," which today is referred to as an interferometer. Much of Michelson's research time at Clark University was spent in pursuing the uses of the interferometer. The interferometer was one of Michelson's most famous inventions and can be simplistically described as a device that splits a beam of light into two parts traveling in different directions and then recombines them such that the difference in their path lengths traveled can be detected. In 1891 Michelson published his technique for using the interferometer to measure stellar diameters and also used the approach to measure the diameters of some of the Jovian satellites. It took until 1920, in collaboration with **Francis Pease** at the Mount Wilson Observatory, for Michelson's dream of measuring stellar diameters to be realized. Together they found the diameter of the star α Orionis (Betelgeuse) to be 47 milli-arcseconds.

Michelson's interest was also caught by Pieter Zeeman's discovery of how magnetic fields influence spectral lines. To explore this effect in greater detail, Michelson invented the echelon spectrometer to provide the resolving power needed to study the effect.

Michelson became a research associate of the Carnegie Institution of Washington in 1924 at the invitation of **George Hale**. At the Mount Wilson Observatory Michelson once again began his experiments in determining the velocity of light. Using projection apparatus located on Mount Wilson, light was reflected back from a receiver on Mount San Antonio some 22 miles away, to determine its velocity. Using this technique he determined the speed of light to be 299,798 km/s. The piers used for this experiment at the Mount Wilson Observatory still stand to this day on a south ridge of the mountain, and a plaque commemorating his experiments is located nearby.

Michelson was not only a man of science but also a Freemason, and he had a well-developed artistic side with many varied interests. He was an avid sketcher and often took his watercolor kit when he went on vacation. Michelson was known to play the violin, enjoy a good game of billiards, and – as a measure of the quality of his health – play tennis until he was past 70 years of age.

Michelson was able to view the beauty of art and nature through science. In a paper he wrote, "On the Metallic Coloring in Birds and Insects," he explored the nature of the metallic colors seen in hummingbirds and certain butterflies. Michelson was able to conclude that their iridescent colors were due to the same effects as the colors reflected from thin metallic films.

Michelson's final experiment was on the same topic on which he began his career, the measurement of the velocity of light. By 1926, he had made more than a thousand measurements of the speed of light using a variety of approaches. Even though the results of these experiments were the best that had ever been made, Michelson was not quite satisfied. For his final experiment he developed a completely new apparatus including a mile long, 3-ft. diameter pipe that could be evacuated of air. The results of this experiment were published in the *Astrophysical Journal* in 1935 by Pease and William Pearson, with Michelson listed as the first author. In this paper they describe the need for the new experiment, which provided a reflective light path through the pipe of eight or ten miles under a vacuum of 0.5 to 5.5 mm of mercury. The result was a measure of the speed of light in a vacuum of 299,774 ± 11 km/s.

To mention just two of Michelson's notable honors, and there are many more, he received the Nobel Prize for Physics in 1907 (the first American to do so in science) for his measurements of the speed of light; he also served as the president of the National Academy of Sciences from 1923 to 1927. Michelson's awards include honorary degrees, medals of merit in science, and membership in scientific societies. There is little doubt that he will continue to be remembered as one of the finest experimental physicists.

Scott W. Teare

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Middlehurst, Barbara Mary

Born **Penarth, Glamorgan, Wales, 15 September 1915**
Died **Houston, Texas, USA, 6 March 1995**

Welsh astronomer Barbara Middlehurst cataloged extant reports of lunar transient phenomena. The reality of these observed changes on the Moon remains controversial. With **Gerard Kuiper** she also edited two multi-volume compendia of astronomical review articles. *The Solar System* in the 1950s and S*tars and Stellar Systems* in the 1960s.

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Mikhailov, Aleksandr Aleksandrovich

Born **Morshansk near Tambov, Russia, 26 April 1888**
Died **Pulkovo near Leningrad (Saint Petersburg, Russia), 29 September 1983**

Alexsandr Mikhailov oversaw the reconstruction of the Pulkovo Observatory. For decades after World War II, Alexsandr Mikhailov was the capable and authoritative leader of the Soviet Union's astronomical community. He was the author and editor-in-chief of numerous publications and a participant in many scientific expeditions.

Mikhailov graduated in 1911 from Moscow University with a Gold Medal. He served as an astronomy professor at this university from 1918 to 1947. Concurrently, Mikhailov was a geodesy professor at what is now the Geodetic University. From 1947 to 1964 he served as director of the world-famous Pulkovo Observatory – the Central Astronomical Observatory of the Soviet Academy of Sciences. In 1964 Mikhailov was given the title academician.

Mikhailov was decorated with a plethora of Soviet and foreign awards, including the highest Soviet decoration, the Medal of a Hero of Socialist Labor (1978). Living permanently under the pressure of his high social status, especially during the Stalin regime, he – unlike many others of his rank at that time – nonetheless never volunteered to harm his colleagues, associates, and subordinates in the style of the political situation of the time.

The area of Mikhailov's personal scientific interests was very broad: astrometry (positional astronomy), stellar astronomy, gravimetry and the theory of Earth's figure, the theory of eclipses, and space research involving the Moon. He was an active solar-eclipse observer and designed several new astronomical devices for eclipse study. A great erudite, Mikhailov wrote much on the history of astronomy and was notable as a popularizer of astronomical knowledge.

An amazingly hardworking person who was fluent in several European languages, Mikailov was an illustrious communicator of Soviet science to the international astronomical community. He was elected as a member of many scientific bodies abroad. Mikailov served as a vice president of the International Astronomical Union (1946–1948), and as a vice president of the International Academy of Astronautics (1967–1977).

It was Mikhailov who oversaw the reconstruction of the glorious Pulkovo Observatory, which had been completely destroyed by the Nazis during the siege of Leningrad during World War II. The observatory was successfully restored as a great symbol of Russian science. Unfortunately, decades later Mikhailov himself became an eyewitness to the slow decline of this internationally acclaimed scientific institution.

Mikhailov married Zdeňka Kadlá in 1946. The couple had a son, Georgij Aleksandrovich Mikhailov.

Alexander A. Gurshtein

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Milankovitch [Milankovič], Milutin

Born **Dalj, (Croatia), 28 May 1879**
Died **Belgrade, (Serbia), 12 December 1958**

Yugoslavian mathematician and geophysicist Milutin Milankovitch is best known for his presentation of the theory that Earth's paleoclimate resulted from interactions of three long-term astronomical cycles affecting the amount of solar energy received by Earth.

Milankovitch was awarded a doctorate in technical sciences from the Technical High School (later the Institute of Technology) in Vienna in 1904. For the next 5 years, he served as a chief engineer in the construction industry, working with reinforced concrete. In 1909, he was appointed to a professorship in physics and celestial mechanics at the University of Belgrade in Yugoslavia, where he remained until his retirement some forty-six years later. Milankovitch was a member of the Serbian Academy of Sciences and other professional organizations.

Starting around 1912, and for the next thirty years, Milankovitch convincingly demonstrated that variations in (1) the eccentricity of Earth's orbit around the Sun and (2) the obliquity of Earth's axis of rotation, along with (3) the precession of the equinoxes, all contributed to cyclical changes in climate experienced over the past 600,000 years, most notably during the Pleistocene glaciation. Because the three variations have different periods (the best-known is the 26,000 years of precession), they sometimes reinforce and sometimes nearly cancel each other, producing large swings in the amount of sunlight reaching the northern hemisphere. These long-term astronomical and climatological cycles are known as Milankovitch cycles and have gained widespread acceptance.

Jordan D. Marché, II

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Miller, John Anthony

Born **Greensburg, Indiana, USA, 16 December 1859**
Died **Wallingford, Pennsylvania, USA, 15 June 1946**

When the Lowell Observatory staff needed help in computing an orbit for the newly discovered planet Pluto, they called upon John Miller, director of the Sproul Observatory. Miller showed that Pluto could not be the "Planet X" proposed by **Percival Lowell**.

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Millikan, Robert Andrews

Born **Morrison, Illinois, USA, 22 March 1868**
Died **San Marino, California, USA, 19 December 1953**

American physicist Robert Millikan's experiments confirmed that subatomic particles arrive at the Earth from extraterrestrial sources. It was he who coined the term "cosmic rays."

Millikan is best known for measuring the charge of the electron and founding the California Institute of Technology. He was awarded the 1923 Nobel Prize in Physics.

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Millman, Peter Mackenzie

Born **Toronto, Ontario, Canada, 10 August 1906**
Died **Ottawa, Ontario, Canada, 11 December 1990**

Peter Millman developed several pioneering programs to observe meteors and to record their spectra. He was the son of Robert M. Millman and Edith Middleton. In 1931, Millman married Margaret B. Gray with whom he had two children, Barry and Cynthia.

Millman spent most of his youth in Japan, where his parents were missionaries. His interest in astronomy developed during his secondary education at the Canadian Academy in Kobe. Millman returned to Canada to enter the University of Toronto, where he took his B.A. in astronomy with the Royal Astronomical Society of Canada Gold Medal in 1929. As an undergraduate, he worked as a summer student at the Dominion Astrophysical Observatory, Ottawa. During his graduate training at Harvard Observatory, **Harlow Shapley** suggested Millman analyze meteor spectra in the observatory's collection. After taking his M.A. (1931) and Ph.D. (1932), he remained another year at Harvard as an Agassiz Fellow.

In 1933, Millman joined the Astronomy Department at the University of Toronto. With the opening of the David Dunlap Observatory in 1935, he participated in the routine radial velocity program but also initiated visual meteor observations and developed a meteor spectra program. Millman joined the Royal Canadian Air Force in 1941; after teaching navigation to pilots, he moved to London to work in operational research. On his return in 1946, he moved to the Dominion Observatory, where he became chief of the Stellar Physics Division and developed a visual meteor program.

From the late 1940s, Millman worked with D. W. R. McKinley of the National Research Council [NRC] of Canada on visual and radar tracking of meteors by triangulation. In the early 1950s, two stations with super-Schmidt cameras were erected in Alberta in a joint United States–Canadian project to study the upper atmosphere. Millman's meteor spectrographs in Alberta and Ottawa produced a steady stream of data. In 1955, Millman joined the NRC as head of its Upper Atmosphere Research Section.

Millman was active in the Royal Astronomical Society of Canada (president: 1960–1962), president of the Meteoritical Society (1962–1966), president of Commission 22 of the International Astronomical Union [IAU] (1964–67), chair of the IAU Working Group for Planetary System Nomenclature (1973–1982), and first secretary of the Canadian Astronomical Society (1971–1977). He was also a fellow of the Royal Society of Canada and a councillor of the Smithsonian Institution. Millman was awarded the J. Lawrence Smith Medal of the United States National Academy of Sciences in

1954, awarded the Gold Medal of the Czechoslovak Academy of Science (1980), and a minor planet (2904) was named for him.

Millman was the world's leading authority on meteor spectra, being the first to undertake systematic spectroscopic studies. Beginning in his Toronto days, he organized visual meteor programs. After World War II, radar and photographic recording of meteor showers were added. During the International Geophysical Year, this became a North America-wide project, providing solid statistics on meteors. Millman was a pioneer in using aircraft for observing meteors and solar eclipses. He collaborated with **Carlyle Beals** on meteorite impact structures, and later devised a program for meteorite recovery.

Richard A. Jarrell

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Milne, Edward Arthur

Born **Hull, England, 14 February 1896**
Died **Dublin, Ireland, 21 September 1950**

British mathematician Edward Milne contributed many of the ideas that have made it possible to analyze the spectra of stars and determine the temperatures, densities, and chemical compositions of their atmospheres, some of those ideas carrying his name. However, he is perhaps more often remembered for a unique cosmological model in which gravitation and electromagnetism followed two different kinds of time.

Milne was the eldest of three sons (all eventually scientists) of a headmaster of a Church of England school, Sidney Milne, and a teacher, Edith Cockcroft. After completion of studies at Hymers College in Hull, Milne won a scholarship at Trinity College, apparently having achieved the highest score to date on the entrance examination. His eyesight made him ineligible for active duty in World War I, but a year and a half after beginning work (in 1914) at Cambridge, he withdrew to work on antiaircraft ballistics research for the duration of the war. Shortly after returning in 1919, Milne was elected a fellow of Trinity College (precluding the need for an advanced degree) and, in 1920, became assistant director of the Solar Physics Observatory under Hugh Frank Newall, the founder of astrophysics at Cambridge. Milne was appointed to the Beyer Professorship of Applied Mathematics at the University of Manchester in 1925 and, in 1929, became the first Rouse Ball Professor of Mathematics at Oxford University, where he and **Harry Plaskett** founded another school of astrophysics.

Milne's work of greatest lasting importance was done at Cambridge and Manchester. He showed that a star in which energy was transported by radiation could not rotate like a solid body, and that the pressure of radiation on atoms with very strong absorption lines (like the violet pair of ionized calcium) would be enough to lift atoms off the surface of a star into its chromosphere. Such "line driving" is now recognized as the cause of winds from cool, bright stars. Working with **Ralph Fowler,** Milne showed that these strong lines are produced very high in the atmospheres of the Sun and stars, and used the Saha equation to calculate the temperature at which lines would be strongest. This, in turn, led to a theoretical explanation of why some spectral features of ionized atoms look stronger in giants than in dwarfs, providing the physical underpinning of stellar luminosity criteria, including an explanation of what the light coming from the Sun ought to look. He pioneered the idea of detailed balance in stellar atmospheres (the idea that the number of transitions between a pair of levels going up and down must have a fixed ratio), leading to what were then called the Milne relations, and derived a form of the equation describing how radiation propagates through stellar gas that also carries his name. His approximation for the opacity of gas to that propagation is still used in calculations to show what the dominant effects must be in the appearance of stellar spectra. And the Milne–Eddington approximation describes absorption features and the stellar continuum as it is being formed together in all layers of the atmosphere.

At Oxford, Milne turned his attention to cosmology, as did many astronomically inclined British mathematicians, in light of **Edwin Hubble**'s discovery of the redshift–distance relation and the increasing familiarity of **Albert Einstein**'s general theory of relativity. Milne and **William McCrea** in 1934 published a set of Newtonian cosmological models that had many of the features of the relativistic ones, but were much easier for most people to understand and are still used as analogies in modern discussions of cosmology. But Milne felt that his most important contribution was what he called kinematic relativity. He started with homogeneity and isotropy (so that every fundamental observer would see not only the same physics but the same history of the Universe) as a basic assumption, not as an observation. Milne believed that he could follow this assumption to a single-model universe that would be the only self-consistent possibility, requiring certain laws for gravitation and so forth. This was not published in final form until his 1948 book, *Kinematic Relativity*. By then he had also incorporated different timescales for gravitational and electromagnetic time, the former a natural logarithm of the latter. Others have returned from time-to-time to these ideas, but so far without much impact on understanding of either the structure of the Universe or the physics in it.

Also at about the time he went to Oxford University, Milne suggested that nova explosions might be caused by the collapse of a normal star to a white dwarf. They are in fact explosions on the surfaces of white dwarfs with close companions, but the suggestion meant that the idea of collapse as a source of rapid energy release was "in the air" when **Walter Baade** and **Fritz Zwicky** put forward the (correct) idea of powering supernovae with collapses to neutron stars.

Milne was elected to the Royal Society (London) in 1926, and received medals from the Royal Astronomical Society (London), the Astronomical Society of the Pacific, and other scholarly organizations. He served as president of the London Maths Society (1937–1939) and suffered a fatal heart attack during a meeting of the Royal Astronomical Society, which he had served as president from 1943 to 1945.

Douglas Scott

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Milton, John

Born **London, England, 9 December 1608**
Died **London, England, 8 November 1674**

Although in no technical sense an astronomer, John Milton, the greatest epic poet of the English language, engaged the new world picture of **Nicolaus Copernicus**, **Galileo Galilei**, and **Johannes Kepler** and imaginatively stretched the boundaries of the canvas upon which it was painted.

Milton's birth coincided roughly with the invention of the telescope. The son of a well-off middle-class Puritan father, he received a rich religious and classical education at Saint Paul's School in London and at Cambridge University. After leaving university, Milton pursued a further period of personal study, and in 1638 embarked on an almost 2-year Grand Tour; this took him to Italy, where he was granted an audience with the aging Galilei. This encounter, in addition to stimulating his awareness of astronomical issues, reinforced Milton's sense of identity as a free Englishman and a Protestant: "I found and visited the famous *Galileo* grown old, a prisoner to the Inquisition, for thinking in Astronomy otherwise than the Franciscan and Dominican licencers thought" (*Areopagitica*, 1644; in Flannagan, p. 1014b).

In the 1640s and 1650s, Milton was an active defender of the antiroyalist position in the English Civil War and the Commonwealth under Oliver Cromwell, writing the official defense of the 1649 execution of King Charles I (*Defensio pro populo Anglicano*, 1651). Soon thereafter, Milton became completely blind, and some of his enemies saw the latter state as divine punishment for his regicidal propaganda. After the restoration of the monarchy in 1660, Milton narrowly escaped with his life, and the rest of his years were spent in relative seclusion. It was principally in this period, from 1660 until his death in 1674, that he produced the greatest of his poetic works, the epic *Paradise Lost* (1667), and *Paradise Regained* and *Samson Agonistes* (published together in 1671).

The narrative of *Paradise Lost* encompasses not only the fall of humankind into sin but also extensive probing of astronomical issues. In Milton's exercise of cosmological imagination, Galilei's influence can be traced in a number of ways. Galilei is the only contemporary of Milton's to be explicitly named in *Paradise Lost*, and his discoveries provided Milton with an abundant store of both poetic and scientific material. For example, Satan's shield is described as being

> like the moon, whose orb
> Through optic glass the Tuscan artist views
> At evening from the top of Fesole,
> Or in Valdarno, to descry new lands,
> Rivers or mountains in her spotty globe. (*PL* 1.287–1.291.)

Milton thus not only alludes to Galilei's telescopic examination (in *Sidereus Nuncius*) of the Moon's surface, but also uses the simile to suggest that Satan's armor, when viewed up close, may, like the Moon, appear less perfect and "celestial" than one had previously thought. Milton again references Galilei's telescopic discoveries – and again associates Satan with the word "spot," implying blemish – in calling the fiend, in his solar journey, "a spot like which perhaps / Astronomer in the sun's lucent orb/Through his glazed optic tube yet never saw" (*PL* 3.588–3.590). Milton nods in the direction of yet a further discovery of Galilei's – that the Milky Way consists of multitudinous stars – when the angel Raphael, speaking to Adam, the first man, refers to "the Galaxy, that Milky Way/Which nightly as a circling zone thou seest/Powdered with stars" (*PL* 7.579–7.581).

Because of suggestions in *Paradise Lost* that the Earth may be in the center of the world, Milton's astronomical position is often wrongly thought to be basically Ptolemaic. However, Milton undermines this premature conclusion in two main ways. One includes the Copernican references and vocabulary that he and his authoritative characters (such as Raphael) employ, even if these appear in the context of similes or surmises. Speaking to Adam, Raphael asks, "What if," in addition to the six planets, "seventh to these/The planet earth, so steadfast though she seem,/Insensibly three different motions move?" (*PL* 8.128–8.130). Earth's status as a planet and its three motions are clearly Copernican, as is Raphael's further reference to Earth "as a star/Enlight'ning her [*i. e.*, the Moon] by day, as she by night/This earth" (*PL* 8.142–8.144).

A final feature of the narrative of *Paradise Lost* that places it in the tradition of Copernicans such as Kepler and **John Wilkins** is its envisaging of the transport of living bodies across astronomical space. As Robert Burton had pointed out in 1638, the dissolution of the Aristotelian "hard and impenetrable" crystalline spheres opened up the prospect of space travel: "If the heavens then be penetrable, … it were not amiss in this aerial progress to make wings and fly up" (*The Anatomy of Melancholy,* Part 2, p. 50). In *Paradise Lost* Satan does just this, though his flight is not upwards from Earth toward the stars, but down through the stars toward the Sun and the Earth. From the rim of the Universe, downward Satan "throws"

> His flight precipitant, and winds with ease
> Through the pure marble air his oblique way
> Amongst innumerable stars, that shone
> Stars distant, but nigh hand seemed other worlds. (*PL* 3.563–3.566.)

J. Tanner has called *Paradise Lost* "perhaps the greatest description of space travel in highbrow fiction." Yet what enabled Milton to produce such a description – and so to contribute to the genre of science fiction, then in its infancy – was his immersion in the cosmological ferment of his day.

Much more cosmologically radical than these generally Copernican themes, however, was Milton's imaginative depiction of our universe of stars, Sun, and planets as itself a mere speck within an immensely larger, perhaps infinite, physical "creation" dominated by the unformed matter of chaos. In Milton's extracosmic chaos, even normal categories of time and space do not apply. It is

> a dark
> Illimitable Ocean without bound,
> Without dimension, where length, breadth, and highth,
> And time and place are lost. (*PL* 2.891–2.894.)

Moreover, these dark, chaotic materials, which are nevertheless of divine origin, may be, or may become, the stuff of new or other "worlds" (*PL* 2.916).

In any case, in the picture presented in *Paradise Lost*, the entire known stellar Universe – regardless whether its internal structural features be Ptolemaic or Copernican – is enclosed in a sphere that hangs down from the walls of heaven. And when Satan, on his journey across chaos, beholds this Universe from afar, it appears as a mere speck, "in bigness as a star/Of smallest magnitude close by the moon" (*PL* 2.1052–2.1053). Such, in the decades just before the advent of **Isaac Newton**'s cosmology, was Milton's imaginative poetic expansion of cosmography outward toward the infinite.

Dennis Danielson

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Mineur, Henri Paul

Born **Lille, Nord, France, 7 March 1899**
Died **Paris, France, 7 May 1954**

Mathematician Henri Mineur played an important role in the development of astrophysics in France. His 1944 recalibration of the zero-point of the Cepheid period–luminosity relationship was unnoticed at the time but presaged the later work of **Walter Baade**. Mineur was the son of Paul Mineur, a mathematics teacher who taught in Lille and later at the Lycée Rollin in Paris, and Léonie Jacquet. Henri was a pupil at the Lycée Rollin along with **Jean Dufay**, who became director of the Lyon Observatory and Haute-Provence Observatory. At 18, Mineur received entry to the École Polytechnique in a good rank, and entry at first rank to the École Normale Supérieure. He chose the latter, but with France engaged in World War I, he went instead into the army. At the war's end in 1919, Mineur returned to his studies, and passed the examination (*l'agrégation*) to teach secondary-school mathematics 2 years later. After passing his doctoral thesis (on the analytic theory of continuous finite groups) in 1924, he spent the following year teaching mathematics at the Lycée Français in Düsseldorf, Germany. In 1925, he took a position as an *astronome adjoint* at the Paris Observatory, directed then by **Benjamin Baillaud**. Mineur was already familiar with the observatory, having served there in 1922/1923 as a trainee under **Paul Couderc**.

After serving various departments at the Paris Observatory, Mineur became involved in the *Carte du Ciel* project, launched in 1887 by **David Gill** and **Ernest Mouchez**. Mineur also researched stellar statistics, a topic that influenced his astronomical career and developed his skills in various domains of astronomy. He earned good reports about his research from others at Paris, including from **Ernest Esclangon**, director at that time.

In 1931, Mineur directed the work of several students, including Li Heng (1898–1989), whose work led Mineur to study stellar fields and clusters. Li Heng worked on the determination of the zero-point of the period–luminosity relationship for Cepheid variables, studied their spatial and velocity distributions, and in 1932 submitted a dissertation on his statistical researches on Cepheids. After Li Heng's departure from France, Mineur pursued and developed this line of research; in 1944, he published a paper giving corrections for the zero-point for classical Cepheids and for RR Lyrae variables. He also noted in a later publication that this result served to multiply the distances to such stars by a factor close to 1.8.

The elections of 1936 in France had given power to the Popular Front, one of whose innovations related to scientific research and led to the appointment of both Irène Joliot-Curie and Jean Baptiste Perrin as Undersecretary of State for Scientific Research. This subsequently led to the creation of a service for research in astrophysics, which comprised the Haute-Provence Observatory (near Manosque in the south of France) and an associated laboratory in Paris. The observing station and the laboratory would later be attached to the Centre National de la Recherche Scientifique [CNRS], established in October 1939. Mineur played a large role in this effort along with **Daniel Chalonge**, an *aide-astronome* at the Paris Observatory after 1933, whom Mineur had previously known as an assistant in the Sorbonne. Mineur later obtained the positions of general secretary of the service and director of the laboratory. Mineur was removed from his position in 1941 by the Vichy government, while he was engaged in the resistance; the laboratory was removed to several different locations. A part of the domain of the Paris Observatory was allotted to it. After World War II, a new laboratory building, constructed in 1952, hosted the newly named Institut d'Astrophysique de Paris. Mineur, still an assistant astronomer at the Paris Observatory, served as its director until his death. He played a large part in centralizing this hitherto widely dispersed astrophysical research, giving France an important role within it.

Mineur, an astrophysicist concerned with the Milky Way, its constituents, and stellar absorption, was also a mathematician who studied relativity, celestial mechanics, and pure mathematics. He was especially engaged with general problems relating to the treatment of data, and wrote a clear, well-written, and widely used book on the technique of least squares. He trained many students, and his courses in stellar astronomy and lectures on the expansion of the Universe enjoyed large audiences.

Mineur was a talented popularizer, helping amateur astronomers mostly through the articles he published in *L'Astronomie,* the magazine of the Société Astronomique de France, which he had joined in his youth. In declining health by 1952, Mineur attended a meeting in Rome during which Walter Baade announced and **Andrew Thackeray** confirmed, that the calculated distances in the Universe had to be multiplied by a factor of 2; on that occasion, **Clabon Allen** recalled Mineur's 1944 paper that had presented a similar result, also from consideration of Cepheid and RR Lyrae variables. Mineur's early death was a deep loss within the ranks of his generation of researchers.

Mineur married twice, to Suzanne Fromant in 1926 and to Gabrielle Cloche in 1929.

Jacques Lévy

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Minkowski, Hermann

Born **Aleksotas, Russia (now Kaunas, Lithuania), 22 June 1864**
Died **Göttingen, Lower Saxony, Germany, 12 January 1909**

German mathematician Hermann Minkowski introduced the concept of "space–time." The Minkowski metric or geometry is the one appropriate to **Albert Einstein's** special theory of relativity.

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Minkowski, Rudolph Leo Bernhard

Born **Strasbourg, (Bas-Rhin, France), 28 May 1895**
Died **Berkeley, California, USA, 4 January 1976**

Rudolph Minkowski made significant contributions to the understanding of gaseous nebulae, was codiscoverer of the two principal types of supernovae, and participated in the early identification of radio sources with their optical counterparts. Son of Oskar Minkowski, a professor of pathology, Minkowski attended German schools in Cologne, Greifswald, and Breslau. He began to study physics at the University of Breslau (1913) and hoped to go to Berlin the following year. These plans were disrupted by war; from 1914 to 1918, Minkowski served in the German army. After that conflict ended, he studied in Berlin, then returned to Breslau, and completed his doctoral thesis under the supervision of Rudolf Ladenburg (1921). After working at Göttingen University for a year with James Franck and Max Born, Minkowski relocated to Hamburg in 1922 and taught at University of Hamburg until 1935, when he was forced to immigrate to the United States.

In 1933, Adolf Hitler seized power in Germany; his National Socialist Party subsequently forbade persons from "non-Aryan" backgrounds to retain employment in official places like universities. In 1935, Minkowski lost his title as professor and was no longer allowed to teach. His father-in-law, judge Alfons David, had been dismissed from the court at Leipzig in 1933. But through the assistance of **Walter Baade**, who had left Hamburg for the Mount Wilson Observatory in 1931, Minkowski first secured a 1-year appointment at Baade's new institution. His position on the Mount Wilson staff was made permanent after his formal dismissal (1936) was received from the University of Hamburg. Thus, from 1935 until 1960, Minkowski worked as a research astronomer at the Mount Wilson and Palomar observatories and (after compulsory retirement) from 1961 to 1965 at the Radio Astronomy Laboratory of the University of California in Berkeley. In 1926, Minkowski married Luise Amalie David; the couple had two children.

Minkowski's research career can be divided into two phases. Prior to his emigration, he had worked chiefly on laboratory spectroscopic problems. His principal subject of investigation was the width of spectral lines, and how they were broadened by pressure and self-absorption. Minkowski published related papers on the behavior of electrons in metallic vapors and the process by which electrons pass through atoms (with Hertha Sponer). His final Hamburg paper (with **Hermann Brück**) described the atomic-beam method of determining the fine structure of spectral lines.

Yet, as early as 1933, Minkowski had turned his attention towards astrophysical problems, including features observed in the spectrum of the Orion Nebula. Upon settling in the United States, his knowledge of spectroscopy proved most useful for studying a variety of astronomical objects. Minkowski's collaboration with Baade led to a rapidly growing number of publications. These included studies on the internal motions of gaseous nebulae and the discovery of almost 200 new planetary nebulae. He and Baade also collaborated on the study of supernovae in other galaxies and supernova remnants in our Milky Way. Minkowski and Baade distinguished supernovae of two types (I and II), based upon their light curves and the presence/absence of hydrogen in their spectra. Their classification scheme also proved useful as a tool for estimating cosmological distances in space (supernovae as "standard candles"). Shortly after the Crab Nebula was recognized as a supernova remnant, Minkowski and Baade identified its small central star (later found to be a neutron star/pulsar). Minkowski also worked on the distribution of emission nebulae in our Galaxy and on the spectral features of comets.

After 1949, Minkowski became intrigued with the new field of radio astronomy. Together with Baade, he began to locate the optical counterparts of newly discovered radio sources. One of the first extragalactic counterparts identified (1954) was the radio source Cygnus A. Minkowski likewise studied the distribution of galaxies and in 1960 identified the galaxy (3C 295) having the highest known redshift (Z=0.45) at the time (prior to the discovery of quasars).

Minkowski was also responsible for the wide-field photographic sky survey conducted by the National Geographic Society and known today as the "Palomar Observatory Sky Survey" [POSS]. This work was done with the 48-in. Schmidt camera on Palomar Mountain and covered the Northern Celestial hemisphere down to a declination of –33°. The POSS has proven to be an invaluable tool for countless astronomers.

Minkowski was chosen a member of the Royal Astronomical Society and the United States National Academy of Sciences (1951). He was awarded the Bruce Gold Medal of the Astronomical Society of the Pacific in 1961 and an honorary doctorate from the University of California at Berkeley in 1968.

Ian T. Durham

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Minnaert, Marcel Gilles Jozef

Born **Bruges, Belgium, 12 February 1893**
Died **Utrecht, the Netherlands, 26 October 1970**

Marcel Minnaert pioneered new techniques in the measurement and understanding of spectral line strengths and chemical abundances in the Sun and stars. Minnaert was the son of Jozef and Jozephina (*née* Van Overberge) Minnaert. Both of his parents were teachers at normal schools. Ever since his birth, Minnaert's father meticulously kept a diary on his only child's education, which provides a clear insight into the intellectual development of young Minnaert. Just before his father's premature death in 1903, Minnaert and his parents relocated to Ghent. In 1910, Minnaert enrolled at the University of Ghent, where he studied biology. Four years later, he was awarded his doctoral degree after completing a thesis on the effects of light on plants, entitled "Contributions à la étude de la photobiologie quantitative."

During his studies, Minnaert associated himself with Flemish students, who wished to change the language of instruction at the university from French to Dutch. This measure was introduced during the German occupation of Belgium during World War I and resulted in an urgent need for teachers at the Dutch-language university. Minnaert then went to Leiden, the Netherlands in 1915 to take up physics. He attended the lectures of leading scientists, especially **Hendrik Lorentz** and Paul Ehrenfest. After his return to Ghent in 1916, Minnaert was appointed as an associate professor of experimental physics.

In 1918, Minnaert had to flee his country, to escape prosecution by the Belgian government. He had been one of the language activists at the University of Ghent and was now accused of collaboration with the Germans. Afterwards, he was sentenced *in absentia* to 15 years of penal servitude. Minnaert moved again with his mother to Utrecht, the Netherlands. Thereafter, his main interest became photometry, or the precise measurements of light intensity. He secured a position at the Heliophysical Institute of the University of Utrecht, which, under the direction of Willem Julius, was engaged in developing new photometric techniques related to solar spectroscopy. Minnaert became an observer at the institute; by 1925 he obtained a second doctoral degree (in physics), having written a thesis on anomalous dispersion, entitled "Onregelmatige Straalkromming" (Irregular ray curvature).

Minnaert applied himself to research in solar physics, especially the formation of the Fraunhofer absorption lines in the solar spectrum. Following **Albertus Nijland**'s death in 1936, Minnaert was chosen his successor in 1937 as professor of astronomy and director of the University of Utrecht Observatory. He converted the observatory into a prominent astrophysical institute for research in solar and stellar spectra.

Minnaert's chief contributions lay in his foundation of the "curve of growth" technique in determining solar chemical abundances by spectral analysis. Along with his concept of "equivalent width" (introduced simultaneously by Harald von Kluber in 1927), this methodology established Minnaert's reputation as an outstanding astronomer. The intensities of spectral lines originate from several different broadening mechanisms, which allows them to exhibit characteristic profiles, with a residual intensity being left at the center. Minnaert introduced the measurement of line intensities in terms of the fraction of energy removed from the adjacent continuum by absorption, a quantity which he expressed as the "equivalent width" of a rectangular (*i. e.*, fictitious) absorption feature.

In 1929, Minnaert investigated how the equivalent width increases with the number of absorbing atoms. By first calibrating **Henry Rowland**'s spectral scale in terms of equivalent width, and then applying an earlier technique of **Henry Norris Russell**, he obtained an empirical result by plotting the equivalent width against the number of absorbing atoms. This relationship was called by Minnaert the "curve of growth," a term reminiscent of his earlier biological studies. Following Wilhelm Schütz's theoretical extension of the "curve of growth" in 1930, Minnaert and his students were able to analyze solar equivalent widths, which yielded explanations for the broadening of solar spectral lines and renewed theoretical understanding of line formation.

By the late 1930s, Minnaert's love of nature and his ability to popularize physics were combined into the three-volume work *De natuurkunde van 't vrije veld* (Physics of the outdoors), which appeared from 1937 to 1940. At the same time, his extensive research on solar physics, in collaboration with Jacob Houtgast and Gerard F. W. Mulders, culminated in publication of the voluminous *Photometric Atlas of the Solar Spectrum* (1940). For several decades, this proved to be a standard reference work. During World War II, Minnaert was imprisoned by the Germans for his vocal left-wing opposition to fascism.

After World War II, Minnaert investigated a variety of subjects, including the temperatures of cometary nuclei, gaseous nebulae, the atmospheric homogeneity of Venus, and lunar photometry. For over 20 years, he revised the photometric atlas of the solar spectrum, initially with a several of young astronomers, later with Houtgast, and in the final stages, with **Charlotte Moore-Sitterly**. This publication, *The Solar Spectrum*, was completed in 1966. Minnaert officially retired in 1963, but remained active as a member of the International Astronomical Union [IAU] commission that established the nomenclature of features on the Moon's farside. He also published a laboratory manual, *Practical Work in Elementary Astronomy* (1969).

During his career, Minnaert received honorary degrees from the universities of Heidelberg, Moscow, and Nice. He was a member of various academies, among which are the Koninklijke Nederlandse Akademie van Wetenschappen, the Koninklijke Academie voor Wetenschappen, and the Letteren en Schone Kunsten van België. For his research in solar and stellar photospectrometry, Minnaert received several international awards, the Gold Medal of the Royal Astronomical Society in 1947 and, in 1951, the Bruce Medal of the Astronomical Society of the Pacific. His engagement in cooperative astronomical research enabled Minnaert to hold the positions of president and vice president of several commissions within the IAU.

In 1928, Minneart married Maria Boergonje Coelingh; the couple had two sons.

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Mīram Čelebī: Maḥmūd ibn Quṭb al-Dīn Muḥammad ibn Muḥammad ibn Mūsā Qāḍīzāde

Born **Istanbul, (Turkey), 1475**
Died **Edirne, (Turkey), 1525**

Mīram Čelebī, one of the most important Ottoman mathematicians and astronomers, attempted to reconcile the mathematical (Ptolemaic) and natural philosophical (Aristotelian) traditions concerning astronomy, while writing astronomical texts that were widely used in the Ottoman Empire.

Mīram Čelebī's grandfather Muḥammad was **Qāḍīzāde**'s son; he married **ʿAlī Qūshjī**'s eldest daughter in Samarqand. His father, the scholar Quṭb al-Dīn Muḥammad, came with his grandfather ʿAlī Qūshjī to Istanbul, where Quṭb al-Dīn married Mīram Čelebī's mother, who was the daughter of Khōja-zāde, a famous scholar and philosopher of that time. His father, who had been a teacher at the Manāstır *madrasa* (school) in Bursa, died at a young age, and so Mīram Čelebī was raised by his grandfather Khōja-zāde. Mīram was educated not only by his grandfather but also by other leading scholars of the time such as Sinān Pasha. Upon his graduation, he taught at several *madrasas* (the Gelibolu, the Edirne ʿAlī Bey, and the Bursa Manāstır), becoming the most prominent figure of his time in the mathematical sciences. Indeed Sultan Bāyazīd II (died: 1512) asked him to be his teacher. Mīram Čelebī was appointed as Qāḍī ʿaskar (a high official in the Ottoman judiciary) of Anatolia during the reign of Yavuz Sultan Selīm I (reigned: 1512–1520); however, shortly thereafter he was dismissed from his post and retired. Towards the end of his life, he went on the pilgrimage to Mecca; upon his return he settled in Edirne. He was buried in the courtyard of the Qāsīm Pasha Mosque.

Mīram Čelebī, most famous for his many works in astronomy, optics, and astrology, was also well known in the fields of history and literature. (He even wrote an important work on hunting.) He wrote in Arabic and Persian (the scientific languages of his time) as well as in Turkish. Among his many students were **Muṣṭafā ibn ʿAlī al-Muwaqqit** and the famous philosopher and historian Ṭashköprülüzāde.

Mīram Čelebī inherited the scientific tradition of the Samarqand School of mathematics and astronomy represented by his great-grandfathers Qāḍīzāde and ʿAlī Qūshjī. He was also greatly influenced by **Ibn al-Haytham**'s methodology in the field of optics (*ʿilm al-manāẓir*) and tended to favor his approach of combining mathematics and natural philosophy over the more mathematical approach of both great-grandparents. In addition, Mīram Čelebī was well informed of the opinions of Kamāl al-Dīn al-Fārisī, **Ibn Sīnā**, and **Fakhr al-Dīn al-Rāzī**, among others.

One of Mīram Čelebī's most important astronomical works is his commentary on the Persian *Zīj-i Ulugh Beg,* also known as *Dustūr al-ʿamal fī taṣḥīḥ al-jadwal*, which was completed in 1499 and dedicated to Sultan Bāyazīd II. Mīram Čelebī incorporated findings from **Jamshīd al-Kāshī**'s *Zīj-i Khāqānī* and ʿAlī Qūshjī's *Sharḥ Zīj-i Ulugh Beg*. The work, written in a didactic style, provided five examples of solutions for calculating the sine of 1°. More than 30 extant copies of the *Dustūr* attest to its widespread use by Ottoman astronomers. Mīram Čelebī's mathematical bent is also indicated by a work in which he calculated the ratio of the highest mountain in the world to the diameter of the Earth, a problem going back to **Naṣīr al-Dīn al-Ṭūsī**.

The most noteworthy work written by Mīram Čelebī on the subject of theoretical astronomy is a commentary on ʿAlī Qūshjī's work *al-Fatḥiyya fī ʿilm al-hay'a.* Unlike his great-grandfather, who sought to eliminate Aristotelian natural philosophy from astronomy, Mīram Čelebī sought to reconcile the mathematical and the natural philosophical in astronomy as he had done in optics. He completed it in 1519 following the request of many of Mīram Čelebī's students when he was teaching *al-Fatḥiyya.* The commentary was both practical and theoretical and was used as a supplementary textbook in the Ottoman *madrasas*. Mīram Čelebī stated his intention to write an appendix to his commentary in which he would analyze the problems pertaining to the models of Mercury and the Moon. Although there is no extant copy of this appendix, it is an indication of the importance of the subject as well as an example of a continuous astronomical tradition to solve difficulties related to **Ptolemy**'s planetary models.

Many of Mīram Čelebī's other astronomical works deal with instruments, including a variety of quadrants. His *Risāla dar Shakkāzī wa Zarqāla az ālāt-i raṣadiyya* (in Persian) examines two astronomical instruments invented by **Zarqālī** and their use in astronomical observations. He also wrote on the calendar, the determination of the direction to Mecca (*qibla*), and various other astronomical problems. His *Risāla fī samt al-qibla* is a comprehensive study on the determination of the *qibla* using astronomical and mathematical calculations. Moreover, in accordance with the tendencies of his time, he wrote original works in the field of astrology, such as *al-Maqāsid fī al-ikhtiyārāt* and *Masā'il-i Mīram Čelebī* (in Turkish).

Throughout his work, Mīram Čelebī placed great importance on rational and empirical evidence for the subjects he investigated. His work in theoretical astronomy was an extension of the Samarqand tradition that his great-grandfather ʿAlī Qūshjī continued with his colleagues and students in Istanbul. Mīram Čelebī especially enriched its mathematical character. His relationships with other members of the Samarqand School who came to Istanbul (such as Sayyid Munajjim and **ʿAbd al-ʿAlī al-Birjandī**) await further research. More information is also needed on his contribution to studies on observations conducted in Istanbul at the time of Sultan Bāyazīd II.

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Mitchel, Ormsby MacKnight

Born **Morganfield, Kentucky, USA, 28 July 1809**
Died **Beaufort, South Carolina, USA, 30 October 1862**

Ormsby Macknight Mitchel, the founder and first director of the Cincinnati Observatory (which briefly housed the largest telescope in the United States), established the first exclusive astronomical periodical in the United States, served as second director of the Dudley Observatory, and became nationally famous as an inspirational lecturer on astronomy. He also enjoyed a distinguished United States army career during the Civil War, reaching the rank of major general.

Born in 1809 in Kentucky on what was then the American frontier, Mitchel was the youngest child of John Mitchel; both his father and his grandfather were surveyors. As a child in Lebanon, Ohio, Ormsby was tutored by his widowed mother, Elizabeth (*née* MacAlister) Mitchel, and a brother-in-law, until he entered a school opened by an elder brother, becoming an active member of the school's Thespian Society and Debating Club. In 1825, Mitchel entered the United States Military Academy at West Point, New York, studying surveying, civil engineering, and practical astronomy in addition to military subjects. After graduating in 1829, he taught mathematics at West Point, meanwhile meeting and marrying a young widowed mother, Louisa (*née* Clark) Trask, in 1831.

In 1832, Mitchel resigned his commission and went to Cincinnati, Ohio, then the fourth largest city in the United States and the most important metropolis not on the Atlantic seaboard. There, he studied law and was admitted to the Ohio bar while working as chief engineer of the Little Miami Railroad, one of the key railway lines being constructed across booming Ohio. In 1836, the newly founded Cincinnati College hired Mitchel to teach mathematics, mechanics, machinery, and astronomy; he also established a civil engineering program, one of the first in the country.

Although slightly built (5 ft. 6 in. and 130 lbs), Mitchel was a charismatic teacher and public speaker who held every audience spellbound. In 1841 and 1842, Mitchel gave a series of public lectures on the solar system to crowds of 2,000 Cincinnati residents. After the last lecture, Mitchel announced he would devote the next 5 years to founding a major astronomical observatory in Cincinnati. He also proposed a novel financing scheme: public subscription of shares of stock at $25 apiece – more than a month's wages for many laborers – for which subscribers would have the privilege beholding the heavens through the observatory's grand telescope. Within a month (on 24 May 1842), the Cincinnati Astronomical Society was formed, announcing more than $6,500 worth of stock had been subscribed. After visiting the finest telescope makers in Europe, Mitchel contracted with the firm of Merz & Mahler of Munich, Bavaria, to buy a 12-in. refractor. When it was mounted in 1845, it stood as the largest telescope in the United States and second largest in the world (surpassed only by the Pulkovo 15-in. refractor in Russia) until 1847, when another 15-in. Merz refractor was installed at Harvard College Observatory.

Having secured the telescope, Mitchel's next challenge was to construct the observatory within which to mount the telescope. He did so, meeting the deadline established in the deed for the property, but only by calling upon volunteer labor from Cincinnati citizens and with a complete dedication of his own time and energy to the project.

By the observatory's completion, however, Mitchel had big problems. As the fledgling institution had no endowment, in 1844 he had promised to serve as its director for a decade without pay beyond his college professor's salary. However, in January 1845, 4 days before the telescope arrived, Cincinnati College burned to the ground, and up in smoke went Mitchel's sole source of support for his wife and seven children as well as for the Cincinnati Observatory.

As a result, Mitchel launched himself into a career as a professional itinerant lecturer in astronomy. His timing was fortunate, as the mid-19th century was a golden age for circuit lecturers. Over the next decade, Mitchel became nationally famous for speaking without notes or visual aids aside from diagrams drawn in the air with a wand; his lectures riveted thousands of listeners in Boston, New York City, Philadelphia, New Orleans – some audiences (according to contemporary accounts) leaping to their feet and cheering as at a sporting or political event. Each year, he toured the nation from November through March when Ohio's observing conditions were poor, further augmenting his income by writing several popular books based on his lectures, among them *Planetary and Stellar Worlds* (1848), *Popular Astronomy* (1860), and *Astronomy of the Bible* (1863).

Less well-known was Mitchel's astronomical research during Ohio's clearer, warmer months. He remeasured the positions of the 2,700 double stars in **Friederich Struve**'s 1827 catalogue, especially those south of the celestial equator that never rose high above Pulkovo's horizon; he resolved many stars Struve had not marked double or triple, discovering the greenish companion to the red giant Antares (possibly his most original scientific discovery). Mitchel also determined the rotation period of Mars, monitored the position of the newly discovered planet Neptune, counted sunspots, measured the positions of planetary satellites, and observed comets and nebulae; in short, routine work typical of visual astronomers in mid-19th century observatories.

More significantly, by 1848, Mitchel was involved in early trials (conducted by the United States Coast Survey under **Sears Walker** and **Alexander Bache**) of the American method of longitudes, using the telegraph to compare local times at observatories hundreds of miles apart to determine their differences in longitude. He also proposed and experimented with a telegraph-type system within the Cincinnati Observatory itself to automate the recording of right ascension and declination for ordinary positional astronomy – the so called American method of transits. For both purposes, he invented an early chronograph, which recorded timings on a rotating flat disk, installing working prototypes at the Cincinnati and Dudley observatories.

Lastly, Mitchel founded the first exclusive astronomical periodical in the United States, the *Sidereal Messenger*. Published monthly from July 1846 through October 1848 (when publication ceased for lack of funds), it was a hybrid research journal and popular magazine, summarizing major findings by astronomers in Europe and the United States, plus detailing work at the Cincinnati Observatory.

In 1857, Mitchel's wife, who had also long been his observing assistant, was paralyzed by a series of strokes. In 1859, weighed down by her care, Mitchel reluctantly accepted an offer to become the second director of the Dudley Observatory in Albany, New York. He replaced **Benjamin Gould** after several years of controversy between the latter and the board of Albany citizens responsible for overseeing the observatory. The position included the luxuries of a house and a regular salary. But in 1861, with the start of the Civil War, Mitchel reentered active military service as a brigadier general in charge of volunteers from Ohio; the day after his departure, his wife suffered her last stroke and died.

Affectionately known in the army as "Old Stars," Mitchel served in several campaigns, the most famous being "the great locomotive chase" in Alabama, in which his men took possession of a train to cut telegraph wires and destroy bridges to disrupt the Confederate army's supply lines. His services earned him the rank of major general of volunteers. Mitchel was placed in command of the Union's Department of the South, at Hilton Head, South Carolina; however, a month later, he was stricken with yellow fever and died.

According to contemporary and later biographers, Mitchel's enduring contribution to astronomy was his oratorical eloquence that inspired hundreds of thousands of listeners and readers with wonder for the heavens – a powerful influence in inspiring wealthy philanthropists and the general populace to found scores of observatories in later 19th-century America.

Trudy E. Bell

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Mitchell, Maria

Born **Nantucket, Massachusetts, USA, 1 August 1818**
Died **Lynn, Massachusetts, USA, 28 June 1889**

Maria Mitchell, the first woman astronomer in the United States, paved the way for women in science. She trained an entire generation of women astronomers who followed her into research as well as teaching. Mitchell played a vital role in the 19th century's more enlightened attitudes about the role of women in American society and science.

One of ten children born to William and Lydia (*née* Coleman) Mitchell, Mitchell was raised in a favorable environment with the intellectual lives of her parents. As members of the Nantucket Quaker Meeting, they encouraged each of their children to read extensively and engage in thoughtful dialogue about what they were learning. At an early age, Mitchell began to help her father with his astronomical observation and computing. Her father was well-known as an astronomer who could be trusted to rate chronometers for the whaling vessels and merchant ships calling at Nantucket. Using a platform on top of their home, and later a similar structure on top of the Pacific Bank where William served as a teller, their observing was not limited to time-keeping work but included various objects in the Solar System and sweeping for comets.

Mitchell's formal education was limited to a few years in a school run by her father, followed by a few years at the Reverend Cyrus Peirce's school. She showed a special aptitude for mathematics from an early age, and learned under Peirce's guidance to the extent of his ability. For several years Mitchell assisted Peirce in the operation of his school before starting her own career as a teacher in a school she organized in 1835.The following year she accepted an additional role as librarian of the new Nantucket Athenaeum.

Mitchell experienced more frequent contact with women in the community as a librarian, but also enjoyed more time for her own studies. She taught herself to read French and German and then mastered the mathematical works of **Pierre de Laplace**, **Joseph Lagrange**, and **Karl Gauss** while continuing astronomical observations with her father when weather permitted. While sweeping the skies on the night of 1/2 October 1847, she discovered a comet near Polaris, now known as C/1847 T1 (Mitchell). This was her fourth independent discovery but the first for which the priority was properly hers. Her father immediately reported it to **William Bond**, director of the Harvard College Observatory. There were other independent discoveries of the same comet within days by others, including the director's son **George Bond** who conceded he had narrowly missed making the discovery himself on the same evening. However, William's immediate action in posting the letter to Bond ensured that the comet was credited to his daughter. The discovery by the young American woman brought her substantial notoriety in Europe as well as America. Mitchell was awarded a gold medal by King Frederich of Denmark.

The fame gave Mitchell the opportunity to increase acquaintances among leading American scientists like **Alexander Bache**, director of the United States Coast Survey [USCS], and **Charles Davis**, newly appointed superintendent of the United States Navy's Nautical Almanac office in Boston. Within 2 years, Davis offered her additional employment as a computer for the new *American Ephemeris and Nautical Almanac.* Mitchell computed ephemeris data for the planet Venus from her home in Nantucket. Bache invited Mitchell to spend one summer in Maine working with USCS observers. She continued in that dual employment as librarian and astronomical computer from 1849 until 1865. With her additional income, Mitchell traveled in the United States, learning first hand how privileged her special position on Nantucket was in comparison with women in other parts of the country. Female self-development and self-reliance was encouraged at the peak of whaling and maritime activity in Nantucket, like no where else in the United States at the time.

Mitchell had more travel opportunities when she was asked to travel as a tutor and chaperone for a Chicago banker's daughter in 1857. Mitchell accompanied the young woman to England where she was welcomed as a visitor to the Greenwich and Cambridge observatories. When the banker's daughter was forced to return to Chicago by her father's crisis during the financial panic of 1857, Mitchell stayed in Europe and visited many noteworthy astronomers including **Angelo Secchi**, **Caroline Herschel**, and **Mary Somerville**.

On her return to America, Mitchell received a 5-in. Clark refractor equipped with a micrometer as a gift "from the women of America" in recognition of her achievements as a woman astronomer. This fine instrument intensified Mitchell's desire to continue in her chosen career as an astronomer. After her mother died, Mitchell and her father moved to Lynn, Massachusetts. She was soon interviewed by a trustee for Matthew Vassar's endowment to establish the first women's college in the United States. As one of the best known women in America, Mitchell was a natural choice for the Vassar College faculty, New York, even though she lacked any formal educational credentials. Mitchell quickly accepted the position and moved with her father to the campus near Poughkeepsie, New York in 1865.

The Vassar College Observatory was equipped with a 12-in. Fitz refractor, one of the largest telescopes in the United States. Mitchell was eager to use the new instrument and valued the opportunity to have an influence in the higher education of women. Her classes in astronomy, though rigorous, were popular and well attended. Her astronomy classes and night observing sessions with the telescope created opportunities for education unlike that available to women in any other institution. With the help of her students, Mitchell conducted visual observation of double stars and planets. Thus, Mitchell's later career in astronomy was primarily as a teacher who empowered women in astronomy and the sciences rather than as a researcher.

Several of Mitchell's students were employed in the field of astronomy. The most noteworthy of these include **Antonia Maury**, **Caroline Furness**, Margaretta Palmer, and Mitchell's successor at Vassar College, Mary Whitney (1847–1921). More importantly, her students who chose to pursue careers in astronomy were important assets for the expansion of American astronomy through the first few decades of the 20th century. Working for **Edward Pickering** as "computers" at Harvard College Observatory, and later at Lick and Mount Wilson Observatories, they contributed greatly through their interpretation, classification, and measurement of spectra, as well as the more routine computations necessary for observational-data reduction.

Mitchell took a second tour in Europe in 1873, but while she visited noteworthy astronomers, she was more interested in the status and education of women. The trip had a marked influence on her subsequent life decisions, and she became more involved in improving the status and opportunities for women in the United States. She helped organize and served as president of the American Association of Women, assumed leadership roles in organizations such as the Social Sciences Association, and was the first women accepted as a member of the American Association for the Advancement of Science.

After she resigned in 1888 from Vassar College, Mitchell returned to her home, where she died. During her lifetime, Mitchell was honored by her election to the American Academy of Arts and Sciences and to the American Philosophical Society.

Thomas R. Williams

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Mizzī: Zayn al-Dīn [Shams al-Din] Abū ʿAbd Allāh Muḥammad ibn Aḥmad ibn ʿAbd al-Raḥīm al-Mizzī al-Ḥanafī

Born **probably al-Mizza near Damascus, (Syria), 1291**
Died **Damascus, (Syria), 1349**

Mizzī was a *muwaqqit* (*i. e*., an astronomer appointed to a mosque who is responsible for regulating the times of prayer), an instrument maker, and the author of numerous treatises on astronomical instruments. He studied in Cairo under the well known physician and encyclopedist Ibn al-Akfānī. He was first appointed as a *muwaqqit* in al-Rabwa, a quiet locality near Damascus, and then at the Umayyad Mosque in Damascus, a position he held until his death. Mizzī authored treatises on the use of the astrolabe, the astrolabic quadrant, and the sine quadrant. In particular his treatises *al-Rawḍāt al-muzhirāt fī al-ʿamal bi-rubʿ al-muqanṭarāt* (On the astrolabic quadrant) and *Kashf al-rayb fī al-ʿamal bi-'l-jayb* (On the sine quadrant) were popular. He also wrote on the use of less common instruments, such as the *musattar* (concealed) and the *mujannaḥ* (winged) quadrants.

Although he made few original contributions to instrument making in particular or to astronomy in general, Mizzī was nevertheless an important and influential authority in the field, whose didactic treatises were appreciated by students of applied astronomy dealing with timekeeping (*ʿilm al-mīqāt*). The instruments he made were highly praised as being the best of his times and sold for considerable prices, namely 200 dirhams or more for an astrolabe, and at least 50 dirhams for a quadrant. Some five quadrants of his fabrication are extant, dated between the years 1326/1327 and 1333/1334. According to the 15th-century astronomer Ibn al-ˁAṭṭār, he also made astrolabes with mixed projections (*i. e.*, with markings obtained by a combination of stereographical projections about the North Pole and South Pole, respectively). According to his biographer al-Ṣafadī, Mizzī also excelled in oiling bows (*baraˁa fī dahn al-qisī*) and impressed his contemporaries by constructing mechanical devices such as those of **Banū Mūsā**.

François Charette

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Moestlinus

➤ **Mästlin [Möstlin], Michael**

Mohler, Orren Cuthbert

Born **Indianapolis, Indiana, USA, 29 July 1908**
Died **Ann Arbor, Michigan, USA, 17 September 1985**

Orren Mohler served as director of the University of Michigan Observatories from 1961 until 1970 and continued as director of the McMath–Hulbert Solar Observatory [MHO] until 1979.

Mohler received his AB in 1929 from Michigan Normal College, followed by an MA (1930) and Ph.D. (1933) from the University of Michigan. From 1933 to 1940, Mohler taught astronomy at Swarthmore College, Pennsylvania, and worked as an astronomer at the private observatory of amateur astronomer Gustavus Wynne Cook (1867–1940). While working for Cook, Mohler conducted observing programs on the spectrographic binary star TX Leonis and on Nova Herculis 1934. He also attempted to improve the quantum efficiency of the Geiger–Muller counter so it could count individual protons.

In 1940, Mohler became the first full-time professional astronomer at MHO of the University of Michigan at Lake Angelus near Pontiac, Michigan. During World War II, Moher worked at MHO on military research and development, including development of the Cashman PbS infrared detector. He later exploited this experience by fitting such a detector to the MHO spectrograph. Working with **Robert McMath**, Mohler was able to extend infrared spectroscopy to well beyond previous limits, but it was apparent that local seeing was preventing full exploitation of the resolution of the excellent grating available. This prompted McMath to seek funding for the first astronomical vacuum spectrograph which, when completed, fully rewarded their effort. Mohler then published an atlas of the solar spectrum from 11,984 Å to 25,578 Å with approximately 100 times greater resolution than any previous spectrum in this region. Mohler was appointed professor of astronomy in 1956. Mohler became director of the McMath–Hulbert Observatory, and in 1962 was appointed as chairman of the Astronomy Department and director of the University of Michigan Observatories.

Mohler's primary interests were instrumentation and the history of astronomy. He was awarded the Naval Ordnance Development Award for his contributions to military research and development, and was a Fulbright Scholar.

Patricia S. Whitesell

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Molesworth, Percy Braybrooke

Born **Colombo, (Sri Lanka), 2 April 1867**
Died **Trincomali, (Sri Lanka), 25 December 1908**

Percy Molesworth, one of the notable British amateurs in the late 19th century, contributed much of our pre-spacecraft knowledge of Jupiter. Molesworth was the son of Sir Guildford and Mary Elizabeth (*née* Bridges) Molesworth. His father, a noted civil engineer, served as a colonial officer in Ceylon. Molesworth was educated in England at Winchester College, Winchester and received a commission in the Corps of Royal Engineers of the British army in 1886. After further education at the Royal Military Academy at Woolwich and Chatham, he served in England and Hong Kong before requesting a return to Ceylon. As captain (later major), Molesworth was stationed in Trincomali. This gave him an ideal location for observing Mars and Jupiter, using a 12.5-in. reflector, in the garden of his house high above the sea.

Molesworth was the most assiduous of all observers of Jupiter. His observations (visual transit timings, especially from 1898 to 1903) contributed greatly to establishing the patterns and permanence of the various currents. In 1900, for example, he recorded 6,758 central meridian transit timings on Jupiter! Molesworth's individual reports were published in the *Monthly Notices of the Royal Astronomical Society*. As a result of his and others' work, all the permanent slow currents that control large circulations on Jupiter had been identified by 1901. Molesworth also noted several phenomena whose importance for the atmospheric dynamics on Jupiter has become recognized in the era of spacecraft: The start of a great south tropical disturbance (discovered in February 1901), the turbulent bright spots west of the Great Red Spot, one of which he saw erupting within less than an hour, and the 90-day oscillation of the Great Red Spot itself. Molesworth also contributed substantial observations and drawings of Mars to the *Monthly Notices*; those that were not published in 1903 are still in the archives of the Royal Astronomical Society.

With his health failing, Molesworth retired in 1906 at the age of 39, intending to continue astronomical observations from his estate in Trincomali; however, he fell ill again and died of dysentery.

John Rogers

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Moll, Gerard

Born **Amsterdam, the Netherlands, 18 January 1785**
Died **Amsterdam, the Netherlands, 17 January 1838**

Dutch astronomer Gerard Moll directed the Utrecht Observatory for 26 years. The son of Gerard, a wealthy Amsterdam merchant, and Anna (*née* Diersen) Moll, he became a junior clerk in an Amsterdam mercantile house around 1800. It was a job he undertook with reluctance but performed satisfactorily. His spare time was devoted to mathematical and scientific studies, including astronomy. After several years, Moll's father allowed him to undertake academic studies at the University of Amsterdam. Moll was awarded a Ph.D. in 1809, and afterwards studied at the University of Paris.

In 1812, Moll was appointed director of the Observatory at the University of Utrecht. Following that institution's reorganization in 1815, Moll was also appointed professor of mathematics and natural philosophy, a post which he held until his death. The university, however, failed to provide much in the way of support or maintenance for the observatory.

In 1825, Moll was offered a chairmanship at the University of Leiden. But he declined the offer after Utrecht administrators evidently agreed to provide substantially greater support. Moll used this opportunity to acquire an improved collection of astronomical instruments and a substantial library. During his Utrecht career, he observed an annular eclipse of the Sun (7 September 1820), a transit of Mercury across the Sun's disk (5 May 1832), and an occultation of Saturn (8 May 1832).

Besides astronomical observations, Moll conducted research in several areas of physics (then called natural philosophy). He extended the work of Hans Christian Øersted after the latter's 1820 discovery of electromagnetism. Moll repeatedly measured the speed of sound and arrived at a value very near the currently accepted figure.

Moll was given further responsibilities by the Kingdom of the Netherlands, concerning flood protection and the observation of tides along the Dutch coast. His comparative study of the British and French systems of weights and measures earned Moll a knighthood of the Order of the Belgian Lion. He was awarded honorary doctorates by the universities of Edinburgh and Dublin.

Hartmut Frommert

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Mollweide, Karl Brandan

Born **Wolfenbüttel, (Germany), 2 February 1774**
Died **Leipzig, (Germany), 10 March 1825**

Astrometrist and mathematician Karl Mollweide is best known for his spirited defense of the Newtonian theory of color. The son of Christoph Mollweide, Karl Mollweide studied mathematics at Helmstadt University beginning in 1796, and in 1800 started teaching mathematics and physics in Halle/Saale, while continuing his studies at the University of Halle. After his graduation from the university in 1811, he became an observer at the university observatory in the old castle of Pleissenburg, and lectured in astronomy. Mollweide was elected professor of astronomy in 1812 and became a professor in mathematics at the University of Leipzig in 1814. From 1820 to 1823 he was dean of the philosophical faculty.

In 1814, Mollweide married the widow of the gatekeeper Knorr, of the hospital gate in Leipzig. Mollweide's wife was sister to the wife of another assistant at Pleissenburg Observatory. After his wife's death in 1821, his sister-in-law took care of his household. Mollweide had a stepson but no natural children by marriage.

Mollweide lived in the tower of the Pleissenburg until 1816. He worked on problems in spherical astronomy (*e. g.* stellar aberration) and astronomical position finding, as well as interpretations of various text passages from astronomers of classical antiquity.

Before his appointment in Leipzig, Mollweide was publicly engaged in defending **Isaac Newton**'s theory of colors. In that regard, he was a dedicated opponent of Johann Wolfgang von Goethe and his *Farbenlehre* (Theory of colors); Goethe never accepted Newton's theory.

Mollweide also wrote mathematical essays on the construction of magic squares, the application of **Carl Gauss**' addition and subtraction logarithms, and on the largest ellipse contained in a square. Two of his outstanding discoveries are still of great mathematical importance today. He calculated the Mollweide projection, which is often applied in the field of cartography when the whole Earth is depicted. He studied Cartesian trigonometry and developed the Mollweide formulae of plane trigonometry or sky, which are used in the calculation of the triangle.

Thomas Klöti
Translated by: *Balthasar Indermühle*

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Molyneux, Samuel

Born **Chester, England, 18 July 1689**
Died **Kew, (London), England, 13 April 1728**

Samuel Molyneux, noted as an instrument maker and observational astronomer, assisted **James Bradley** in the latter's studies that led to the discovery of the aberration of light. The only son of the astronomer **William Molyneux** and Lucy Domville, Molyneux was raised by his uncle, Thomas after both parents died while he was a young boy. Educated at Trinity College, Dublin (BA: 1708, MA: 1710), Molyneux studied meteorology and was elected to the Royal Society in 1712. He became a member of parliament in 1715 (elected again in 1726 and 1727).

In 1717 Molyneux married Lady Elizabeth Capel, who inherited money and an estate at Kew, to which the couple moved. Caught by the enthusiasm of **John Hadley** for optics, Molyneux turned his scientific interests to making optical components and instruments. His design for a Newtonian reflector set the standard of construction for such instruments. He conducted experiments to find the best alloy for speculum metal by testing 150 alloys of varying compositions. Between 1723 and 1725, Molyneux worked on reflecting telescopes with **James Bradley**, then Savilian Professor at Oxford (later Astronomer Royal).

In 1725, with Bradley, Molyneux ordered a large zenith sector from instrument maker **George Graham**, in order to investigate the large parallax of γ Draconis reported by **Robert Hooke**. Molyneux and Bradley set the telescope up in Molyneux's house in Kew, looking through holes in the roof. They observed γ Draconis in December 1725 and found a large shift in position as the month progressed. However, it was in the wrong direction to be a parallactic shift; as the two continued observing through the year they saw a large annual circular motion. Bradley ordered a larger, more versatile zenith sector from Graham and erected this one at the house of Molyneux's aunt in Wanstead in August 1727. By December, Bradley had made accurate measurements by which he inferred the phenomenon of the aberration of light.

Meanwhile, Molyneux's political interests took more of his time. He became a member of the Irish Parliament in 1727 and a lord of the admiralty, ceasing work in astronomy. Molyneux died at a young age of a stroke, presumably as a result of a medical problem inherited from his mother who also died early of a brain disease.

Paul Murdin

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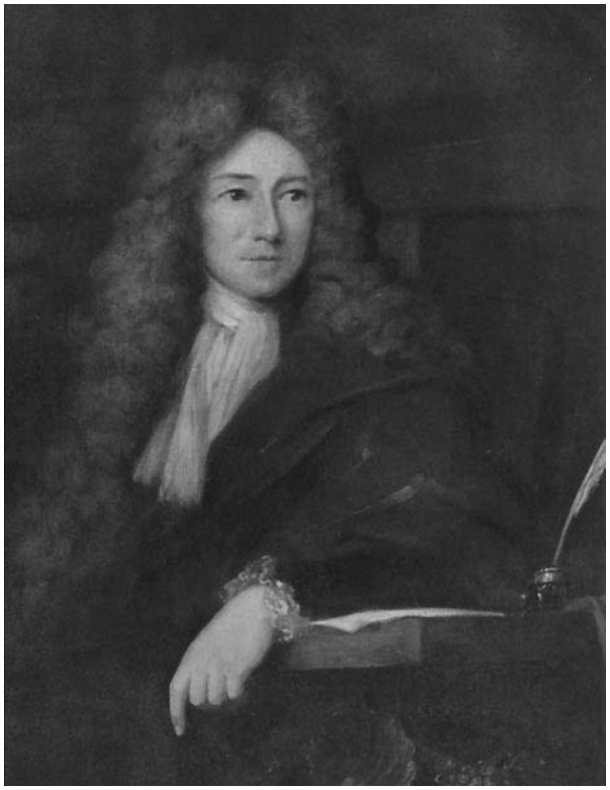
Molyneux, William

Born **Dublin, Ireland, 17 April 1656**
Died **Dublin, Ireland, 11 October 1698**



William Molyneux, an influential figure in the scientific affairs of Dublin in the late 17th century, gained the respect of **Edmond Halley** and **John Flamsteed** as an astronomer and wrote *Dioptrica Nova*, the first major book in English on optics.

William was the eldest surviving son of Samuel Molyneux and Margaret, daughter of William Dowdall, of Dublin. The Molyneuxs became part of the protestant establishment that dominated Dublin social and political life. Samuel, trained as a lawyer, was a skilful artillery officer, experimenting with gunnery for many years. William received a good schooling and entered Trinity College, Dublin, at the age of 15. After graduating he went to London in 1675 to study law. However, law did not interest Molyneux greatly, and he devoted most of his time to applied mathematics and science. He returned to Dublin in 1678 and married Lucy, the youngest daughter of Sir William Domville, Attorney General of Ireland. Only 2 months later, she became ill, becoming blind and suffering from constant headaches until her death 13 years afterwards. After a vain search in England for medical relief for his wife, Molyneux settled down in Dublin and passed the time by translating **René Descartes**'s *Méditations*, published in London in 1680. He also translated **Gallileo Galilei**'s *Discorsi* from Italian for his own use.

Molyneux's wife's affliction probably led him to pose the Molyneux problem, which assumes that a man blind from birth who gains his sight is confronted by a sphere and a cube that he had previously learnt to distinguish by touch. Can he identify at first sight which is which? Molyneux believed not. John Locke, George Berkeley, and other philosophers discussed the problem.

Molyneux's first important achievement in astronomy was to record the lunar eclipse seen in Dublin on 1 August 1681. He sent his observations to a friend in London, Charles Bernard, who passed them on to Flamsteed, the Astronomer Royal, whom Molyneux had previously visited at Greenwich. This led to a correspondence between Flamsteed and Molyneux that continued for the next ten years in which problems of optics, astronomy, ballistics, and tides were discussed. Molyneux learned a great deal about optical instruments from Flamsteed's letters; the exchanges were remarkable for their cordiality, as Flamsteed was reputed to have a short temper.

In 1684 Molyneux became involved in a controversy between **Robert Hooke** and **Johannes Hevel**. In his *Machina coelestis* (1673), Hevelius had claimed that open sights were better than telescopic sights. Hooke vigorously disputed the claim and, in 1679 Halley went to Danzig to test the rival theories. Halley supported Hevelius and gave him a written testimonial to that effect. Hevelius repeated his claim in 1685, in his *Annus Climactericus* which Molyneux reviewed, showing Halley's conclusions were invalid and telescopic sights were more accurate.

In October 1683 Molyneux and some colleagues from Trinity College formed a society on the model of the Royal Society of London. It was called the Dublin Philosophical Society; it met in rooms owned by an apothecary and included a garden for plants and a laboratory. Sir William petty was the first president, and Molyneux was secretary. The society exchanged minutes with the Royal Society and the Oxford Philosophical Society. Papers read in Dublin were frequently published in the *Philosophical Transactions of the Royal Society*. The society was the forerunner of the Dublin Society (1731) that became the Royal Dublin Society (1820), promoting the utilitarian aims of the original society.

In 1685 Molyneux was elected a fellow of the Royal Society. That same year he visited his brother Thomas (afterwards Sir Thomas) who was studying medicine in Leiden, the Netherlands. The brothers visited **Christiaan Huygens** at The Hague where he showed them a telescope in his garden and a planetary clock. In Paris they visited **Jean Cassini** and saw a clockwork device for driving a telescope.

Returning through London, Molyneux visited Flamsteed, and he also ordered the construction of a combined dial and telescope of his own design, to which he gave the name *Sciothericum telescopicum*. Flamsteed later examined the device and was not impressed. The following year Molyneux published a book describing the instrument.

When James II arrived in Ireland in 1688, Molyneux fled to England, settling in Chester. There, his son **Samuel Molyneux** was born; he was a source of great interest and pride to his father and became an astronomer.

During his 2-year stay in Chester, the elder Molyneux wrote *Dioptrica Nova,* which was the first book on optics published in English. The book was received favorably and became a standard text. In a dedication to the Royal Society he made a complimentary reference to Locke, which led to a long and friendly correspondence between the two men.

After the defeat of James II in July 1690, Molyneux returned to Dublin and became involved in politics. He was elected as one of the university representatives in the new Irish parliament in October 1692 and was reelected in 1695. As a result of his concern about the effect of the English parliament's legislation on the linen and woolen industries in Ireland, early in 1698 he published the work by which he is generally best known: *The Case of Ireland's being bound by Acts of Parliament in England*, *stated.* It was an attempt to prove the legislative independence of the Irish parliament, and it provoked strong opposition from the English parliament.

Despite the unfavorable reaction to his book in England, Molyneux went to London in July 1698 to fulfill a long-standing promise to visit Locke. Upon his return in September, he soon suffered a recurrence of a kidney complaint and died.

Ian Elliott

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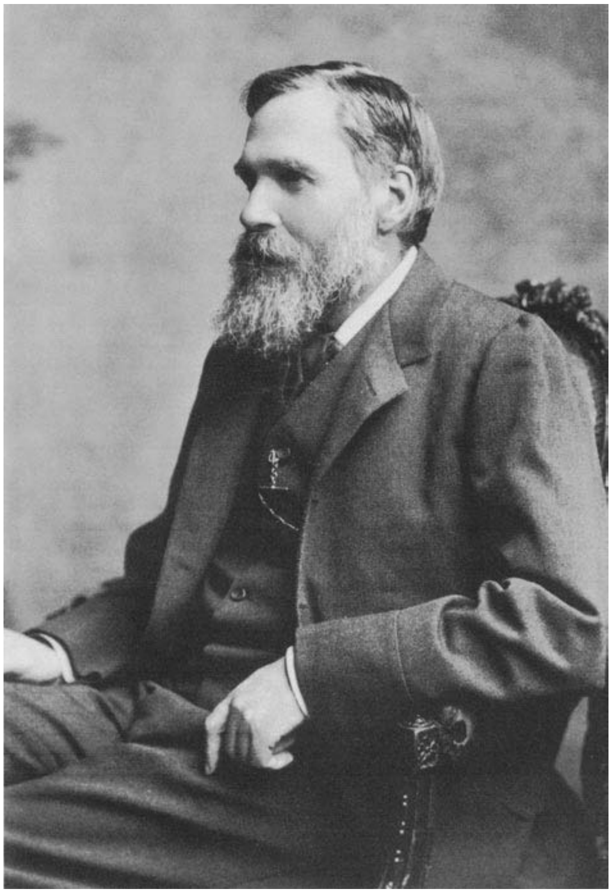
Monck, William Henry Stanley

Born **Skeirke near Borris-in-Ossory, (Co. Laois), Ireland, 21 April 1839**
Died **Dublin, Ireland, 24 June 1915**

Although trained as a lawyer and philosopher, William H.S. Monck was a highly proficient amateur astronomer who was among the first to realize the existence of dwarf and giant stars. With the assistance



of Stephen M. Dixon, Monck made the first astronomical photoelectric measurements of light in Dublin in August 1892.

Monck was the third of four sons of the Reverend Thomas Stanley Monck (1796–1858) and his wife Lydia (*née* Kennedy). His childhood was spent in a rural community 16 miles southeast of Parsonstown (now Birr), King's County, where **William Parsons**, the Third Earl of Rosse, completed the great 72-in. reflecting telescope in 1845. The sight of the Leviathian of Parsonstown may well have kindled Monck's interest in astronomy.

The Anglo–Norman family Monck that settled in Ireland descended from William Le Moyne (living in 1424) of Devonshire and his son Robert. From 1705 the Monck family was associated with the Charleville estate near Enniskerry, County Wicklow. William's grandfather, the Reverend Thomas Stanley Monck, was a younger brother of Charles Stanley, the First Viscount Monck. Charles, the Fourth Viscount Monck, was Governor General of Canada from 1861 to 1868.

William Monck was educated at home by tutors. He distinguished himself on entry to Trinity College Dublin, and in 1861 he obtained the first scholarship in science with a gold medal and a first class honors degree in logic and ethics; he also received the Wray Prize for the encouragement of metaphysical studies. He studied divinity with distinction for several years. However, instead of following his father and grandfather into the Anglican Church of Ireland, Monck turned to law and was called to the bar in 1873. He was later appointed chief registrar in bankruptcy in the High Court in Dublin. In 1878 Monck returned to academic life and was professor of moral philosophy in Trinity College (the chair formerly occupied by George Berkeley) until 1882. He wrote *An Introduction to Kant's Philosophy* (1874) and a well-received *Introduction to Logic* (1880).

In 1886 Monck became a fellow of the Royal Astronomical Society [RAS] and a member of the Liverpool Astronomical Society. On 12 July 1890 he wrote a letter to the *English Mechanic* advocating the formation of an association of amateur astronomers to cater for those who found the RAS subscription too high, or its papers too technical, or who, being women, were excluded. Moves toward setting up such a society had already been made by **Edward Maunder**, and the British Astronomical Association was established at a meeting in London on 24 October 1890.

Monck was a prolific writer, and from 1890 onwards many of his letters and articles appeared in the early volumes of the *Publications of the Astronomical Society of the Pacific*, *The Sidereal Messenger,* and *Astronomy and Astro-Physics* (the forerunner of the *Astrophysical Journal*), as well as the *Journal of the British Astronomical Association* and the *English Mechanic*. In 1899 he published *An Introduction to Stellar Astronomy,* which consisted mainly of articles that had previously appeared in *Popular Astronomy.*

In 1891 Monck purchased a 7½-in. refractor designed by **Alvan Clark** that had been owned previously by the Reverend **William Dawes**, Frederick Brodie, and Dr Wentworth Erck. Monck erected the telescope in the back garden of his residence at 16 Earlsfort Terrace, Dublin. Shortly afterward he received a request from his old college friend, George M. Minchin (1845–1914). Minchin, a professor of applied mechanics at the Royal Indian Engineering College at Cooper's Hill, London, wanted to test "on the stars" some selenium photocells that he had developed. Using a quadrant electrometer borrowed from Trinity College to record the voltage produced by the cell, Monck and his neighbor, professor Dixon, succeeded in measuring the relative brightness of Jupiter and Venus on the morning of 28 August 1892. They failed to obtain "certain" results from the stars on account of instrumental drift and other difficulties. Minchin continued to improve his cells. Working with professor **George FitzGerald** of Trinity College and William Edward Wilson (1851–1908), Minchin made measurements of stellar brightness in April 1895 and January 1896 using the 24-in. reflector operated by Wilson at Daramona Observatory in County Westmeath. These observations were reported by Minchin in *The Proceedings of the Royal Society.*

In 1894 Monck suggested that there were probably two distinct classes of yellow stars – one being dull and near, the other being bright and remote. He based this on his examination of several catalogs that displayed the early Harvard Observatory spectral classifications as well as proper motions for large numbers of stars. What Monck noticed was that those stars comparatively close to the Earth (and therefore exhibiting the largest proper motions) were not also the brightest stars. In fact, the 92 stars he identified as Capellan (modern spectral classes F and G) and the 59 Arcturian stars (modern spectral class K) had large proper motions and were about equal in brightness to the Sirian stars, of which there were only 11 of the same brightness and proper motion. Monck concluded, properly, that this meant that the Sirian stars were likely intrinsically brighter but farther away on average. This clue to the existence of dwarf and giant stars was taken up by his friend **John Gore** who estimated the size of Arcturus. If better data had been available to Monck, his discussion of proper motions and spectra might have led him to the relationship between luminosity and color later discovered by **Ejnar Hertzsprung** and **Henry Norris Russell**.

Monck may have been the first to suggest the parsec as a unit of distance. In his *An Introduction to Stellar Astronomy* (1899), he wrote:

> If we adopted as our unit of distance that of a star with a parallax of one second (in other words 206,265 times the distance of the Sun), the distance of any other star will be 1/p, where p is the parallax expressed as a fraction of a second. This would, I think, be a more convenient unit of distance than that usually adopted by astronomers; *viz*., a year's light passage, or the distance which light travels in a year.

Monck was greatly interested in meteors; he corresponded with **William Denning** for many years. Monck wrote 39 articles or letters related to meteors in the current journals over 3 decades (1885–1914).

David DeVorkin has described Monck as a "brilliant amateur astronomer," but probably very few of his contemporaries realized the potential impact of his astronomical studies. Quiet and reserved in manner, he was an authority on politics, history, and legal matters. Monck took a great interest in educational matters and supported all schemes for improving the lot of the underprivileged. He was a formidable chess opponent but took more pleasure in solving problems than in the cut and thrust of games.

Ian Elliott

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——— (1892). "The Photo-Electric Effect of Starlight." *Astronomy and Astrophysics* 11: 843.

——— (1895). "The Spectra and Colours of Stars." *Journal of the British Astronomical Association* 5: 416.

——— (1899). *An Introduction to Stellar Astronomy: with illustrations*. London: Hutchinson and Co. (Especially p. 51 for the quote on the origin of the parsec.)

Monnier, Pierre-Charles le

Born **Paris, France, 23 November 1715**
Died **Herils, Calvados, France, 3 April 1799**

Pierre Le Monnier, an outstanding observational astronomer, brought English astronomical ideas and instrumentation to France. Le Monnier's father (also named Pierre) was professor of philosophy at the Collège d'Harcourt and member of the Académie royale des sciences. His brother, Louis Guillaume Le Monnier, also an academician, was professor of botany at the Jardin du roi, physician (*premier médecin ordinaire*) to King Louis XV and King Louis XVI, and a physicist. In 1763, Pierre-Charles married a daughter of the wealthy Norman family of Cussy, with whom he had three daughters, one of whom married **Joseph de Lalande**, another who married Pierre Charles' brother Louis.

Le Monnier began his astronomical career early with the assistance of his father. As early as 1731, when Le Monnier was still quite young, he indicated his skill with observations of the opposition of Saturn. In 1732, he was allowed to observe in Paris. In 1735, Le Monnier presented an elaborate lunar map to the academy and was admitted as *adjoint géomètre* on 23 April 1736. By 1746, he rose to *pensionnaire* and became professor of physics at the Collège royal (Collège de France). He was eventually elected to the Royal Society of London, the Berlin Academy, and the Académie de la Marine.

Mainly as an observer, Le Monnier greatly advanced astronomical measurement in France. He was a favorite of Louis XV, who procured for him some of the best astronomical instruments in France. Le Monnier studied the Moon, determined the positions of many stars, conducted extensive research in terrestrial magnetism and atmospheric electricity, and wrote about astronomical navigation.

Le Monnier's career accelerated with the geodesic expedition of 1736 to Lapland. He accompanied **Pierre de Maupertuis**, **Alexis Clairaut,** and the Swedish astronomer–physicist **Anders Celsius** to measure a degree of an arc of meridian at high latitude. The equipment of the expedition included a 9-ft. zenith sector, a transit instrument, and a clock, all by **George Graham**, the leading English maker of the day. In addition to surveying the degree of meridian, Le Monnier made observations of atmospheric refraction at various latitudes and in different seasons.

In 1741, Le Monnier published his *Histoire céleste* as a review of observations made in France from the founding of the Académie royale des sciences. The transit instrument he describes there and illustrates in detail was designed by Graham. Le Monnier introduced his *Description* by relating it to that previous account of the transit instrument, to Maupertuis' account of the zenith sector, and to the general textbooks written by Nicolas Bion in France and Robert Smith in England. Le Monnier thought that the mural quadrant was capable of being a universal instrument for all fundamental measurements in astronomy. Intimately familiar with the English mural quadrants, having acquired one of 5-ft. 4 in. radius from Jonathan Sisson in 1743, Le Monnier had also examined the original Graham quadrant in detail at Greenwich in 1748, and obtained a similar instrument of 8-ft. radius from John Bird in 1753. It was clear that, as the mural quadrant was becoming the principal instrument in the observatories of Europe, so London makers were moving into a position where they dominated the market in precision instruments. Le Monnier played an important part in this process, especially in relation to France, and his *Description* is one of its most impressive monuments.

Then Le Monnier published *La théorie des comètes* (1743), which was largely a translation of **Edmond Halley**'s *Cometography* but with several additions, and constructed the first transit instrument in France at the Paris Observatory and the great meridian at the Church of Saint Sulpice, Paris, also during the year 1743.

In 1748, Le Monnier travelled to England and observed an annular eclipse of the Sun in Scotland. An indefatigable observer, he undertook a star catalog and in 1755 produced a map of the zodiacal stars. He made several observations of Uranus before it came to be recognized as a planet by **William Herschel** in 1781. In fact, the third Astronomer Royal, **James Bradley**, recorded Uranus as a star in 1748, 1750, and 1753, while **Tobias Mayer** sighted it in 1756. But Le Monnier recorded Uranus 12 times between 1764 and 1771, including six observations in January 1769. Apparently he did not recognize Uranus, which was near its stationary point in the sky at the beginning of 1769, so its movement among the stars would not have been obvious.

Le Monnier introduced two constellations, now obsolete. The Reindeer (*Le Renne* or *Tarandus Vel Rangifer*) was created in 1743 for commemorating Lapland. Some faint stars between Camelopardalis and Cassiopeia formed it. The Solitary Thrush (*Le Solitaire* or *Turdus Solitarius*) was an Indian bird created in 1776 near the tail of Hydra.

Le Monnier's work on lunar motion was the most extensive and the most important of his time. In the first edition of the *Principia*, **Isaac Newton** had shown that the principal inequalities of the Moon could be calculated from his law of universal gravitation; in the second edition Newton applied these calculations to the observations of **John Flamsteed**. His methods, however, added little to the theory that **Jeremiah Horrocks** had suggested long before. Flamsteed calculated new tables based on Horrocks' theory incorporating Newton's corrections, but he did not publish them. They appeared for the first time in *Institutions astronomiques* (1746), Le Monnier's most famous work. It was basically a translation of **John Keill**'s *Introductio ad veram astronomiam* (1721), but with important additions and with new tables of the Sun and the Moon. The textbooks of Lalande and **Nicolas de La Caille** later largely replaced this book, which was the first important general manual of astronomy in France.

Le Monnier supported the view of Halley that the irregularities of the Moon's motion could be discovered by observing the Moon regularly through an entire cycle of 223 lunations, which is the Saros cycle of approximately 18 years and 11 days, with the assumption that the irregularities would repeat themselves throughout each cycle. Le Monnier and Bradley each began such a series of observations; Le Monnier continued this work for 50 years.

During the 1740's Clairaut, **Jean d'Alembert**, and **Leonhard Euler** were racing to create a satisfactory mathematical lunar theory, which demanded an approximate solution to the difficult three-body problem. In the ensuing controversy, Le Monnier seconded d'Alembert who used Le Monnier's *Institutions astronomiques* as the basis for his tables. In 1746, Le Monnier presented a memoir to the academy describing his observations of the inequalities in the motion of Saturn caused by the gravitational attraction of Jupiter. His results were important for improving the lunar theory, because a good explanation of the perturbations of Saturn also required a treatment of the three-body problem.

The best lunar tables of the 18th century were those of Tobias Mayer, which were based on Euler's theory but with the magnitude of the predicted perturbations taken from observations. Although Le Monnier admired English methods in astronomy, he adhered to the task of correcting Flamsteed's tables even while confessing the superiority of Mayer's.

As a regular correspondent with Bradley, Le Monnier was apparently the only astronomer with a sufficiently long and sufficiently accurate enough series of stellar observations to verify Bradley's discovery of the nutation of the Earth's axis in 1748. Le Monnier was the first to apply nutation in correcting solar tables.

Le Monnier's most prominent pupil was Lalande, who attended his lectures in mathematical physics at the Collège Royal. To determine lunar parallax, Lalande, on Le Monnier's strong recommendation, went to Berlin in 1751 to take measurements of the Moon for comparison with those taken by La Caille at the Cape of Good Hope.

Christian Nitschelm

Alternate name

Lemonnier, Pierre-Charles

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Monnig, Oscar Edward

Born **Fort Worth, Texas, USA, 4 September 1902**
Died **Fort Worth, Texas, USA, 3 May 1999**

Oscar Monnig functioned as an active amateur astronomer as well as a publisher of an astronomical newsletter that provided an important link between members of the North American community of amateur astronomers. As a collector of meteorites, he assembled one of the largest and most diversified collections in the world.

Monnig was one of three sons of William and Alma (*née* Wandry) Monnig. His father and uncle, George B. Monnig, founded Monnig Wholesale, Inc., a successful dry goods business that eventually grew to include five retail department stores in the Fort Worth area. Monnig finished his formal education at the University of Texas at Austin earning an LL.D. degree in 1925. After practicing law for 5 years, Monnig joined the family business. He succeeded his brother Otto in 1974 as chief executive officer of the company, continuing in that capacity until the business was sold in 1983, by which time his health had begun to deteriorate.

Monnig's first love was astronomy. He always insisted on calling himself an "amateur," having had no formal training in any related field. He once signed up for a course in astronomy in college, but the class was cancelled for lack of enrollment; therefore his knowledge was all from individual study. Monnig was part of a small band of dedicated observers that included Robert Brown, James Logan, Sterling Bunch, and Blakeney Sanders. Together, they founded the Las Estrellas Observatory under dark skies south of Fort Worth. Work at the observatory emphasized variable star and meteor observing, photographic observation of comets and planets, and lunar occultation timing. With the advice of Canadian astronomers **Peter Millman** and Ian Halliday, gained during a solar eclipse expedition in August, 1932, Monnig successfully captured early spectrographic images of meteors by placing a prism in front of a camera lens. The group's meteor work was so regular and of such high quality that **Charles Olivier** began identifying them as the "Texas Observers", and the title was adopted by the group.

In 1928, Sterling Bunch published two issues of a newsletter that he titled *The North Texas Astronomical Bulletin*, but his effort floundered for lack of writers. In 1931, Monnig restarted the publication, but titled it *The Texas Observers Bulletin*, as an informal newsletter that carried various observations about astronomical subjects "of interest to amateurs." Monnig continued the publication of this bulletin until 1947. It was mimeographed and mailed in standard business envelopes to more than 200 subscribers around the United States and Canada. In some issues, Monnig would include photographic prints of interest in the envelope, but would leave space on the mimeographed page for the photograph to be pasted in after it was received by the subscriber. The *Texas Observers Bulletin* was recognized favorably by such professionals as **Otto Struve** and **Bart Bok**, who encouraged similar efforts on the part of other amateurs.

Over time, Monnig's astronomical interest became strongly focused on meteoritics, a field that he chose because "it was a small area where he could find joy." His most lasting legacy is the internationally recognized meteorite collection that he amassed. The Monnig Meteorite Collection is now housed in the Department of Geology at Texas Christian University in Fort Worth. His collecting started in the early 1930s when meteorites were mere curiosities and the idea of making a collection of these objects was alien to most people. Because the family business required his visiting large areas of the United States southwest, Monnig left word that he would buy any "strange rock that turned out to be a meteorite" as he traveled. As a result he bought many "hen-house door stops" from ranchers and farmers. Also, an important opportunity to collect fresh meteorites occurred when newspapers or radio would report a "fireball." Monnig would try to establish where a possible fall would have occurred and would then go there at the first opportunity, sometimes successfully finding meteorites. Over time and his travels, he built up a network of observers and meteorite hunters around Texas, Oklahoma, and Arkansas. Monnig encouraged others to get involved by publishing a small but well-written brochure describing the appearance and physical characteristics of a meteorite together with information on how to contact him when a suspected meteorite was found. When Monnig could not visit the area of a possible fall, he frequently solicited the help of Robert Brown who traveled to the area to coordinate a search. When a new discovery was made, Monnig often teamed up with **Harvey Nininger**, one of the few other meteorite collectors in the early days. Because his duties as a businessman were primary, Monnig's impact on science exists largely in his collection of many rare meteorites that otherwise might have been lost.

Monnig was one of the charter members of the Society for Research on Meteorites (later known as the Meteoritical Society). In addition to being a fellow of the society, he served as a councilor from 1941 to 1950 and from 1958 to 1966; he also served as the society secretary from 1946 to 1950. In 1984, Monnig was honored as the first recipient of the Texas Lone Star Gazer Award.

On 2 January 1941, Monnig married Juanita Mickle whom he met while pursuing a meteorite fall in East Texas; they had no children.

Arthur J. Ehlmann

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Montanari, Geminiano

Born **Modena, (Italy), 1 June 1633**
Died **Padua, (Italy), 13 October 1687**

Geminiano Montanari was the first to recognize the variability of Algol. The son of Giovanni Montanari and Margherita Zanasi, he was left fatherless at age 10. Montanari began his studies in Modena. After an agitated youth, at 20 he went to Florence to study law; he remained there for 3 years. After one of the frequent and violent quarrels he had during his life (to testify a strong character), Montanari left Florence and moved to Salzburg, Austria, where he took a law degree in 1656.

During a stay in Vienna, where he carried on legal practice, Montanari befriended Paolo del Buono, **Galileo Galilei**'s pupil and Florentine diplomat at the imperial court. With his help Montanari took up mathematical and scientific studies, which always interested him.

After a long journey in Austria and the eastern Carpathians, Montanari returned to Italy in 1658, dropped law, and became astronomer to the Grand Duke of Tuscany. In 1661, he returned to Modena as astronomer to Duke Alfonso IV d'Este. There

Montanari married Elisabetta, who collaborated actively with him. Montanari also met the Marquis Cornelio Malvasia, the duke's military chief who was interested in astronomy. In 1649 Malvasia had called the young **Gian Domenico Cassini** to Bologna. Montanari observed with Cassini in Malvasia's private observatory at Panzano, near Bologna. The collaboration produced a large volume, the *Ephemerides novissimae motuum coelestium*, published by Malvasia in 1662.

Montanari became skilled in the design and construction of astronomical instruments including good objective lenses. (One, dated 1666, is in the Museo della Specola in Bologna.) He was one of the first to invent the bifilar micrometer, which he used to draw a lunar map for Malvasia's *Ephemerides*. A device for the exact positioning of telescopes was described in *La livella diottrica* (The leveling diopter) of 1674.

In 1664, with Malvasia's assistance, Montanari obtained the chair of mathematics at the University of Bologna, where Cassini had been teaching astronomy since 1650. His Bologna years were the happiest of his life; he became a promoter of Bolognese cultural development.

In 1667, Montanari discovered that the star Algol (β Persei) was fainter than usual. Between 1668 and 1677 Montanari followed the variability of Algol, sending his results to the Royal Society of London. He also gave a description of Algol's variability in his 1671 *Sopra la sparizione d'alcune stelle ed altre novitá celesti* (On the disappearance of some stars and other celestial novelties), in which he also reported his suspicion of the variability of the star now known as R Hydrae. Montanari perceived neither the regularity nor the period of variation of Algol because of the deterioration of his eyesight, which prevented regular observation. These observations by Montanari struck another blow against Aristotelian immutability, still in contention decades after Galilei's *Sidereus Nuncius*. Montanari's ideas on this phenomenon, which were contrary to popular opinion, were thus violently attacked. Montanari's observational diaries, including his Algol observations, passed to **Francesco Bianchini** and **Eustachio Manfredi**, who recorded them in Bianchini's *Astronomicae ac geographicae observationes* (Verona, 1737); unfortunately the diaries were later lost.

Montanari was also a keen observer of comets and other celestial phenomena, as demonstrated by the observations he made of the meteor that crossed the sky of central Italy in 1676 or those of the comet of 1682, the same observed by **Edmond Halley**. He believed comets to be above the Moon, *pace* the Aristotelians, because he was able to measure the parallax (with a telescope equipped with a micrometer) and the distance, confirming **Tycho Brahe**'s and Cassini's observations. He mistakenly maintained that meteors are similar to lightning and that rocks sometimes found at impact sites are terrestrial in origin.

Typical of natural philosophers of this period, Montanari was also interested in many other natural phenomena. In physics, Montanari experimented on the behavior of liquids in capillary tubes, ascribing it to the major or minus capacity of liquid to stick to the matter of a vessel, which became the topic of a decade-long polemic against Donato Rossetti. Montanari also undertook biological and medical experiments, including blood transfusion between animals in 1668 at Udine. Interested in meteorology, Montanari studied tornados and was the first to use the term "atmospheric precipitation." He noted the utility of the barometer for weather forecasting and as an altimeter. Montanari also devoted himself to ballistics, writing a short manual in which the gunners could find tabulated values for elevations corresponding to gun-ranges. He also worked in hydraulics, leaving the results of his work to his pupil Domenico Guglielmini. With the help of Bolognese and Paduan intellectuals Montanari published several tracts intended to discredit astrological prognostication.

Montanari organized and promoted the Accademia della Traccia (derived from the Florentine Accademia del Cimento), important for scientific debate and for instruction that he gave to his best pupils. It is clear from his works that he was an authentic Galilean, and he maintained a position based on a clear distinction between "metaphysics" and "natural philosophy."

In 1678 Venice created a chair of astronomy and meteors at Padua. Lured by a large salary, Montanari took the position. In addition to teaching, for which he was famous for clarity and scientific rigor, he performed other duties for the Republic, from inspection of rivers and the protection of the lagoon of Venice, to fortifications, artillery training, and organization of the mint and monetary problems. Due to all these duties, some dangerous to his health, Montanari became blind. He died suddenly of an apoplectic stroke.

Fabrizio Bònoli
Translated by: *Giancarlo Truffa*

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Moore, Joseph Haines

Born **Wilmington, Ohio, USA, 7 September 1878**
Died **Oakland, California, USA, 15 March 1949**

American stellar spectroscopist Joseph Moore has as his monuments a catalog of the radial velocities of all northern stars brighter than visual magnitude 5.51, compiled with **William Campbell**, and the third, fourth, and fifth editions of the definitive catalog of orbital elements of spectroscopic binaries. He was the only child of John Haines and Mary Ann (*née* Haines) Moore. In 1907, Moore married Fredrica Chasa, a Vassar College, New York, graduate who had come to Lick Observatory as a computer; they had two daughters, Mary Kathryn (Gates) and Margaret Elizabeth (Matthews). Moore received his postsecondary education at Wilmington College, whence he graduated AB in classics in 1897, and at Johns Hopkins University, from which he received his Ph.D. in 1903. He was elected to the United States National Academy of Sciences in 1931 and was a fellow (and in 1931 vice president) of the American Association for the Advancement of Science. Moore twice served as president of the Astronomical Society of the Pacific (1920 and 1928) and was vice president of the American Astronomical Society in 1942.

Moore came from a Quaker family and remained a lifelong member of the Society of Friends. Although he began his postsecondary education in the field of classics, Moore was influenced in his last year at Wilmington College by W. W. Bennett, who taught

astronomy there and encouraged him to use the 12-in. reflector belonging to the college. At Johns Hopkins University, Moore studied astronomy under **Simon Newcomb** and physics under **Henry Rowland**, J. S. Ames, and **Robert Wood**. His doctorate was awarded for studies of the spectroscopy of the fluorescence and absorption of sodium vapor. At graduation, Moore was offered by Ames the choice of instructorships in physics at Harvard, Yale, or the University of California (Berkeley), or the position of assistant in spectroscopy at Lick Observatory under Campbell. He chose the latter although the salary was lower, and joined the staff of Lick Observatory on 1 July 1903. Moore was promoted to assistant astronomer in 1906. From 1909 to 1913, he was astronomer-in-charge of the Lick Obervatory's southern station in Chile. On his return, he was promoted to associate astronomer in 1913, and astronomer in 1918. He held the position of assistant director from 1936 to 1942 and was director from 1942 to 1945. Although Moore relinquished the directorship, for medical reasons, in November of 1945, he continued as astronomer and also taught courses at Berkeley until 1948.

Moore's first major task at the Lick Observatory was to assist Campbell in the determination of the radial velocities of all stars brighter than visual magnitude 5.51 that were observable from the Lick Observatory. This resulted in a major catalog in Volume 16 of the *Publications of Lick Observatory*. In 1932, he published *A General Catalogue of the Radial Velocities of Stars, Nebulae, and Clusters* (the predecessor of **Ralph Wilson**'s later catalog). Moore was author or joint author of three of the five *Catalogs of Spectroscopic Binaries* published by the Lick Observatory – a task that the present writer, although he never met Moore, eventually inherited from him. The last catalogue of which Moore was an author (with F. J. Neubauer) was published shortly before Moore's death. All these catalogs remained important reference works to other astronomers for several decades.

Moore took part in five expeditions from the Lick Observatory to observe total solar eclipses. Three were within the United States, one in Mexico, and one in Australia. All but the Mexican expedition, for which the weather was poor, were successful and produced useful results. Moore was in charge of the last two expeditions, in California in 1930 and to Maine in 1932. Moore's special interest in eclipses was the study of the spectrum of the solar corona. This spectrum had been first observed by **Charles Young** during the eclipse of 1868. Until 1931, when **Bernard Lyot** succeeded in observing the corona without waiting for a total eclipse, its spectrum could be observed only during the brief moments of totality. Moore's work thus helped to lay the foundations of our knowledge of the solar corona and of the physical conditions of the matter within it. Campbell and Moore also discovered the doubling of the emission lines in spectra of some planetary nebulae, which they attributed to rotation, but which is now understood as evidence for expansion of the nebulae.

Alan H. Batten

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Moore-Sitterly, Charlotte Emma

Born **Ercildoun, Pennsylvania, USA, 24 September 1898**
Died **Washington, District of Columbia, USA, 3 March 1990**

Spectroscopist Charlotte Emma Moore-Sitterly devoted her professional career to atomic spectroscopy, providing a wealth of vitally needed basic astrophysical data. Moore obtained a BA degree in mathematics from Swarthmore College, Pennsylvania, USA, in 1920. (She would be awarded an honorary doctorate in 1962.) After graduation, Moore moved to Princeton University Observatory, where she became a computational assistant to **Henry Norris Russell**, the director. She also attended graduate courses at the university. Thus began a lifelong association with Russell, until his death in 1957, and Moore's work in two broad, largely separate, fields of fundamental astrophysics.

Russell was engaged in the determination of physical properties of binary stars and on the analysis of stellar spectra based on laboratory data. The first centered on the analysis of eclipse light curves and radial velocity variations for binary stars with the aim of determining accurate masses and radii with which to compare stellar models. The data also yielded dynamical parallaxes for many of the systems (over 1,700) that supplemented trigonometric parallax determinations, especially those compiled at Yale University. The summary monograph resulting from this extended study (1940) served for decades as the standard compilation of fundamental dynamical properties for stars.

The second, atomic spectroscopy, is the field with which Moore is most closely associated. On her arrival at Princeton, she was put to the task of identification of atomic lines in stellar spectra. Laboratory spectroscopy saw a rapid advance in the last quarter of the 19th and first quarter of the 20th centuries. The introduction of electric furnaces, improved vacuum technology, broad wavelength sensitivities of photographic plates, and availability of high-resolution diffraction gratings and long-focus cameras paralleled improvements in sample purity produced for laboratory analysis. In astrophysics, however, quantitative analysis of stellar spectra had not yet started. Progress was hampered by low resolution and poor sensitivity, and by barely developed theoretical means for handling line formation in stellar atmospheres.

This began to change around the time of Moore's arrival at Princeton. By 1920, line identifications were available for a significant number of lines in the solar spectrum and, by extension, to a broad range of stellar spectra. Although lacking a firm theoretical basis with which to explain the appearance of these spectra, the still nascent quantum theory – represented by the Bohr atom and Sommerfeld's explanation of fine structure – at least provided some organizing principles. The analysis was extended to the Stark effect and Zeeman effect, all of which showed that similar groups of lines could arise from coupled energy levels. The recognition of the spin quantum number in 1925, and rapid progress on a vector model of the atom by Alfred Lande, set the stage for Moore's most valuable contributions. (The vector mode was elaborated by Russell and **Frederick Saunders** – so called spin-orbit or L–S coupling.) These were the multiplet table of the elements and compilation of atomic energy levels.

There were two critical steps involved here. First, accurate ionization energies were required to provide a zero point to the energy levels for each element and the identification of the ground-state (resonance) transitions. By the early 1930s, extensive laboratory intensity and wavelength tables were available through Massachusetts Institute of Technology, California Institute of Technology, and other laboratories; the largest sets were the so called Harrison and Paschen tables. But these were limited by the relatively low temperatures that could be achieved in sparks and furnaces. In contrast, the Sun has been used as a standard for spectroscopic measurements, since the discovery of the absorption spectrum by **William Wollaston** and **Joseph von Fraunhofer** early in the 19th century.

Spurred by the accumulation of laboratory data, particularly by **Robert Bunsen**, **Gustav Kirchhoff**, **Norman Lockyer**, and others, **Henry Rowland**, between 1895 and 1897, published the first wavelength list of the photosphere on the Ångstrom scale with identifications for 39 elements (of which several were later shown to be spurious) between 2,975 Å and 7,350 Å. This served as the benchmark list.

The construction of the Snow telescope at Mount Wilson, the first dedicated observatory in the United States for solar spectroscopy and imaging, provided an opportunity to update the list as new spectra covering the same wavelength range became available. Moore was hired by **Charles St. John** to assist with the task. She remained at Mount Wilson from 1925–1928, holding the job title of "computer."

Laboratory standards had by then produced an absolute scale, and this was adopted for the line list. The published list contained identifications for 57% of the detectable lines and assignment of 57 elements. Moore continued her work at Mount Wilson through 1932, and obtained her Ph.D. from the University of California at Berkeley in 1931 with a thesis on sunspot spectra. This represented a major step in the analysis of the solar spectrum, since both magnetic-field data and lower-temperature species (including molecules) were observed. The list was published in 1932 and 1933.

Moore returned to Princeton in 1931 as a research assistant (1931–1936) and then as a research associate (1936–1945), working mainly with Russell and remaining until 1945 when she moved to the National Bureau of Standards [NBS] to work in the spectroscopy section that was headed by William Frederick Meggers. During her second sojourn at Princeton, she married the physicist Bancroft Sitterly and was awarded the second Cannon Prize of the American Astronomical Society for her thesis work.

The product of this period of Moore's life, *A Multiplet Table of Astrophysical Interest*, became the fundamental reference for all astrophysical line identifications. It assigned spectroscopic terms and energy levels to almost 26,000 lines for up to the second ionization state of elements through thorium. First appearing in 1933 in the *Princeton University Observatory Publications* (under the title "Spectrum Lines of Astrophysical Interest"), it was revised twice, in 1945 and again in 1972. The last was issued by the NBS and received very wide circulation. It was soon followed by *An Ultraviolet Multiplet*, which extended the line lists and analyses into the vacuum ultraviolet [UV]. Also resulting from this effort was a series on atomic energy levels, which went through several revisions after first issue by NBS in 1949, a compilation that served as a basic reference for all spectrum predictions.

The utility of these publications extends far beyond their original intention – without these lists, modern stellar atmospheres analyses would be impossible. After Moore's death, they were merged with critically evaluated atomic energy levels and quantum mechanical line strengths to become the National Institute of Science and Technology [NIST] electronic database of atomic line identifications. When the UV spectral window opened after World War II, through the use of sounding rockets and (ultimately) satellites, the UV multiplet table became an indispensable guide to the new territory. Although frequently mentioned as a critical need in her publications, no similar multiplet table was produced for the infrared during Moore's lifetime. Her tables still are widely cited by atomic physicists and chemists, as well as astronomers.

The final step in the evolution of Moore's analyses of the Sun came in 1966 with the publication of the line strengths and wavelengths in the combined solar spectrum using equivalent widths based on the intensity-calibrated tracings obtained at the University of Utrecht, the Netherlands. The work, which was sponsored by a resolution of the International Astronomical Union [IAU], formed the basis for the determination of elemental abundances in the Sun. By its completion, around 24,000 lines were measured with identifications for almost 73%.

Moore remained at NBS, now the NIST, until her retirement in 1968. Thereafter, she joined the Naval Research Laboratory [NRL] and remained affiliated with NRL until her death. She was awarded the Meggers Prize of the Optical Society of America (1972) and the Bruce Medal of the Astronomical Society of the Pacific (1990). She served as vice president of the American Association for the Advancement of Science (1952) and IAU Commission 14 (1961–1967).

Steven N. Shore

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Morgan, Augustus de

Born **Madura (Madurai, Tamil Nadu, India), 27 June 1806**
Died **London, England, 18 March 1871**

Though not an astronomer, Augustus de Morgan, one of the most notable British mathematicians and logicians of the 19th century, served the Royal Astronomical Society in leadership positions for over 3 decades, including his service on the council, and as secretary and editor of the *Monthly Notices*. His influence on the organization and its members was substantial and positive.

De Morgan's father John was a lieutenant colonel in the British Army in India. Born with only one eye, de Morgan was raised in England. Though he did poorly at school, at the age of 16 de Morgan entered Cambridge University where he studied under George Peacock, professor of astronomy and geometry, and **William Whewell**, with both of whom he remained friends. Peacock, along with **John Herschel** and Charles Babbage, formed the Analytical Society famous for introducing to Cambridge advanced German and French methods of calculus and helping to develop a purely symbolic algebra. De Morgan took his BA in 1826, but because of his strong objections to the theological test required at Cambridge, he did not get a fellowship or proceed to the MA. He read for the bar in London but, in 1828, with no mathematical credentials, he was awarded the first professorship of mathematics at the new University College, London. De Morgan held the post until 1831 when he resigned on a matter of principle; he held the post a second time from 1836 to 1866, when he resigned, again on a matter of principle, once again on theological strictures, but now applied to others rather than to himself.

The publication of de Morgan's *Elements of Arithmetic* (1831) was a significant advance in providing a mathematically rigorous yet philosophically sophisticated treatment of number and magnitude useful for scientific applications. De Morgan coined the term "mathematical induction" to differentiate once and for all the purely formal technique of advancing from number n to $n+1$ (used in mathematical proofs) from the purely empirical method of hypothetical induction in science. He saw the far-reaching applications of algebraic and numerical analysis to science, and was himself fascinated by purely algebraic and numerical applications to purely empirical problems; it was he, for instance, who produced the first almanac of Full Moons (from 2000 BCE to 2000) and showed how probability theory can be used, for instance, in predicting catastrophic events in life, a technique in use today by insurance companies throughout the world. His *Trigonometry and Double Algebra*, first published in 1849, provided the first thoroughly geometric interpretation of complex numbers, which further extended their application in engineering and astronomical calculations.

De Morgan also made important contributions to symbolic logic; he saw, more than any other British luminary of the time (except, perhaps, George Boole), that logic as it had been passed down from **Aristotle** was severely handicapped in scope, due in large part to a paucity of rigorous mathematical symbolism. He showed that many more valid inferences are possible than were envisioned by Aristotle, using formulas such as the ones now known as De Morgan's Law:

$$\sim (p \vee q) = \sim p \wedge \sim q, \text{ and } \sim(p \wedge q) = \sim p \vee \sim q.$$

These laws of converses and contradictions state, in English, that the truth value of the negation, or contradictory, of the disjunction of two propositions, is the same as the conjunction of the negation of each of the propositions; likewise, the truth value of the negation, or contradictory, of the conjunction of two propositions is the same as the disjunction of the negation, or contradictory, of each of the propositions. In his *Formal Logic*, de Morgan uses the important new concept of quantification of the predicate to solve problems that were simply unsolvable in classical Aristotelian logic; when Sir William Hamilton accused him of stealing the idea from him, de Morgan replied that it was Hamilton who was the plagiarist, a charge that seems to have been settled in de Morgan's favor. His *Budget of Paradoxes*, published in 1872 and reprinted in 1954 with a new introduction by the great philosopher of science, Ernest Nagel, is a paradigm debunking book; in it, de Morgan shows step by step the fallacies by which frauds, cranks, and pseudoscientific tricksters continue to this day to titillate the public with extraordinary but ultimately false claims.

De Morgan became a fellow of the Royal Astronomical Society in 1828, joining the council in 1830. He was twice secretary of the society (1831–1838, 1848–1854). Though he was asked to become president of the society, he declined on the basis that, in his view, only practicing astronomers should assume that responsibility. In 1837 de Morgan married Sophia Elizabeth Frend, daughter of a mathematician/actuary.

Daniel Kolak

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Morgan, Herbert Rollo

Born **near Medford, Minnesota, USA, 21 March 1875**
Died **Washington, District of Columbia, USA, 11 June 1957**

Yale University's Herbert Morgan prepared the N30 Catalog (1952), providing proper motions for 5,268 stars, updated since **August Kopff**'s *Fundamental Katalog des Berliner Astronomischen Jahrbuch*.

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Morgan, William Wilson

Born **Bethesda, Tennessee, USA, 3 January 1906**
Died **Williams Bay, Wisconsin, USA, 21 June 1994**

American spectroscopist William Wilson Morgan gave his name both to the Morgan–Keenan–Kellman [MKK] system of classification of spectra of stars and to the Johnson–Morgan [UBV] system of measuring stellar colors. Both are still in use.

Morgan's town of birth no longer exists. He was the son of Protestant home missionaries, and as a result of the family's itinerant life style, received his schooling at home, in Florida, Colorado, and Missouri, before finishing high school in the nation's capital. A Latin teacher in Missouri first turned his attention to astronomy with a view of the Moon through a theodolite mounted near a library window. Morgan, whose mother had been born in Virginia, started college at Washington and Lee University (Lexington, Virginia) in 1923 and had planned to complete a degree in English there. But his physics and astronomy professor, Benjamin Q. Wooten, spent the summer of 1926 at Yerkes Observatory and learned that the director, **Edwin Frost** (a spectroscopist who had been nearly blind for some years), needed an assistant to obtain daily spectroheliograms as part of the observatory's routine work.

Morgan was offered the job, and took it up, over his father's objections, in fall 1926. He remained at Yerkes Observatory the rest of his life. Morgan completed a BS in mathematics and physics (largely by correspondence) at the University of Chicago in 1927, and a Ph.D. in 1931, working with **Otto Struve** (who had succeeded Frost as director at Yerkes), with a thesis on the spectra of type A stars displaying a variety of spectral peculiarities, now called Ap stars and known to have strong magnetic fields that facilitate concentrations of rare elements like europium on their surfaces. Morgan was appointed an instructor in 1932 and progressed to full professor, becoming department chair at Chicago for 1960 to 1966 and director of both Yerkes Observatory and McDonald Observatory (1960–1967). He held a distinguished service professorship (1966–1974) and an emeritus position the rest of his life. He served as editor of the *Astrophysical Journal* from 1947 to 1952. Morgan's own Ph.D. students at Chicago included at least 16 who became professional astronomers, including J. Allen Hynek and **Armin Deutsch**.

Morgan's approach to stellar classification and measurement was an innovative, morphological, process-based one. He did not seek to calibrate any particular features in terms of stellar temperature, density, or composition. Rather, working with **Philip Keenan** and Edith Kellman, he chose specific stars to be standards of each type, and other stars were typed by comparing their spectra (obtained with similar telescopes and spectrographs) with a set of images of the standard ones. Their *Atlas of Stellar Spectra with an Outline of Spectral Classification* was published in 1943, with revisions in 1951 and 1973 by Morgan and Keenan. In the early 1950s, together with Harold L. Johnson (died: 1980), Morgan developed a three-color system for stellar photometry. The V color was nearly equivalent to the traditional visual magnitude, B was a blue color (but longward of the Balmer jump), and U (for ultraviolet) was shortward of the Balmer jump. The spectral classes and the color system together were an extraordinarily powerful tool for stellar astrophysics. The spectral type revealed what the intrinsic color and brightness of a star must be, and then the measured UBV brightness revealed the distance to the star, how much reddening and absorption of light had occurred along the way, and something about the abundances of heavy elements in the star.

With graduate students Stewart Sharpless and Donald Osterbrock, Morgan applied these techniques to measure the distances to clusters and associations of hot (OB) stars in the plane of the Milky Way. They announced in 1951 that these associations were concentrated in a few spiral arms, showing clearly for the first time that the Milky Way is a spiral galaxy, as had been suggested half a century before by **Cornelis Easton**. The discovery of a spiral pattern in the distribution of hydrogen gas in the galactic plane from its radio emission at 21 cm both confirmed and unfairly eclipsed their work.

Beginning in the 1950s, Morgan also turned his attention to galaxies. He and **Nicholas Mayall** were able to show that the integrated spectrum of a galaxy contains a good deal of information about the kinds of stars that contribute most of the light (typically populations of giants and supergiants of different ages and compositions). Morgan also worked on a more morphologically based system for the classification of the appearance of galaxies, independent of that evolved by **Edwin Hubble**. An important aspect of the system was the recognition of the special status of the very large galaxies found at the centers of some rich clusters, to which he assigned the types N (meaning nucleated) and cD (meaning supergiant, diffuse; the letter c having been the label given to supergiant stars by **Antonia Maury** some 60 years before).

Morgan received medals or other awards from the United States National Academy of Sciences, the Royal Astronomical Society, the American Astronomical Society (serving as vice president; 1968–1970), and the Astronomical Society of the Pacific. He was a member or associate of scientific academies in the United States, Denmark, Belgium, and Argentina and of the Pontifical Academy of Sciences. He married in 1928 Helen Barrett (died: 1963), the daughter of Yerkes astronomer Storrs Barrett, and, in 1966, Jean Doyle Eliot.

William Sheehan

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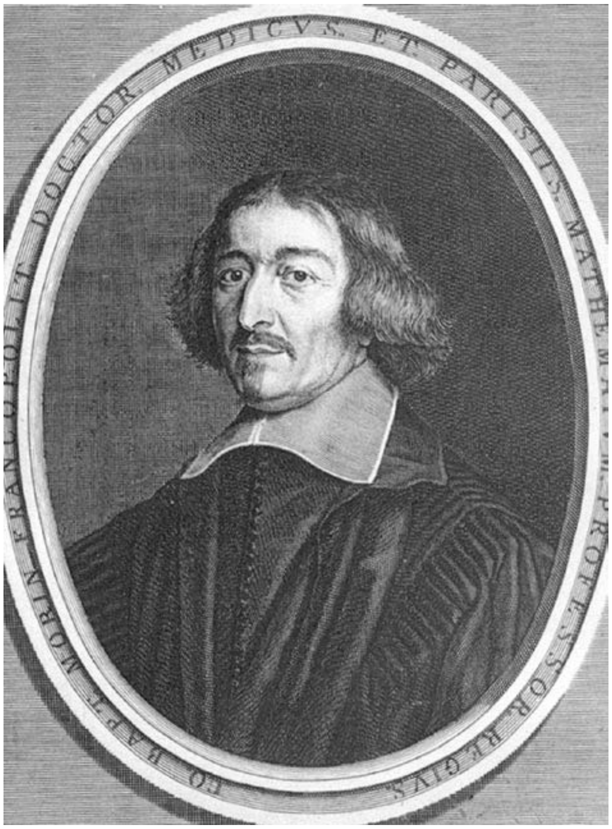
Morin, Jean-Baptiste

Born **Villefranche-sur-Saône, (Rhône), France, February 1583**
Died **Paris, France, 6 November 1656**

Jean-Baptiste Morin, a noted astrologer and notorious controversialist, defended **Johannes Kepler**'s elliptical orbits while at the same time attacking **Nicolaus Copernicus**'s heliocentric cosmology. Baptized on 23 February 1583, his birthdate is unknown. Little is known of Morin's family origins, and he never married. After studying philosophy with Marc Antoine at Aix-en-Provance (1609–1610), Morin took degrees at Avignon (BA: 1611, MD: 1613) where he likely met **Pierre Gassendi** and began his studies with the provincial astronomer **Joseph Gautier**. Always successful in attracting patronage, Morin was first supported by Claude Dormy, Bishop of Boulogne, who sent him to Germany and Hungary to visit mines and to conduct research on metals. Thereafter, Morin received patronage from Leon d'Albert, Duke of Luxembourg, before finally being appointed professor of mathematics at the Collège royal, a post he held from 1630 until his death. It is likely Morin received this appointment through Cardinal Richelieu, no doubt due to his skill in astrology. Quarrelsome in his disputes, Morin consistently opposed Copernicanism and the New Science.



As an astronomer, Morin is chiefly remembered for his efforts to determine longitude at sea. The ensuing debate – like the whole of Morin's career – was surrounded by bitter controversy. His first public pronouncement came in 1633 in a conference at Théophraste Renaudot's Bureau d'adresse, and thereafter a string of pamphlets added fresh fuel to a debate that dominated the decade. Morin's method was sound in principle but impractical. Derived in part from the methods of **Gemma Frisius** (employing spherical triangles but rejecting the use of clocks), it differed in emphasizing the measurement of lunar distances from a fixed star. But the method required especially accurate ephemerides and precise observations of angular distances. The controversy involved the most celebrated astronomers of the day, and given the influence of Richelieu, several commissions were established that included Abbé Chambon, Claude Mydorge, Étienne Pascal, Pierre Hérigone, and later Jean de Beaugrand. Despite receiving 1,000 livres to develop a suitable quadrant, Morin failed to demonstrate his theory. For his part, Morin boasted he had discovered new methods for finding parallaxes and refractions, the equation of time, the height of the pole, the obliquity of the ecliptic, and for determining the more subtle lunar motions.

Morin's public humiliation soon spawned new controversy. Shifting the debate from longitude, Morin launched a barrage of attacks against Copernicanism and atomism, sometimes defending **Aristotle** (1624) against the mechanical philosophy. Morin railed against **Galileo Galilei**, **René Descartes**, and a dozen others, particularly Gassendi and **Ismaël Boulliau**. Significantly, Morin's arguments against Copernicanism were rooted in astrology, and here he endorsed the Tychonic model. As astrologer and champion of the anti-Copernicans, Morin nevertheless embraced **Johannes Kepler**'s elliptical orbits, further asserting he had improved Kepler's methods and the accuracy of the Rudolphine Tables. **Thomas Streete** and **Nicolaus Kauffman** (Mercator) apparently agreed.

Driven by ambition and animosity, Morin's career tells us a good deal about the troubled context of the New Science. The most important polemicist of his generation, Morin seemed to pick his battles on the basis of political advancement, not scientific merit. As a *caractère mélancolique,* he frequently called his opponents "imbeciles," "imposters," and "ignorant buffoons" as well as "plagiarists," "pygmies," and "pathetic pretenders." Vehement and vulgar, his attacks wreak with scatological references. For himself, Morin reserved the rarified title "Complete Restorer of Astronomy." Boulliau, who did his best to ignore Morin, called him the *astronome papier* (paper astronomer). But Morin's published attacks soon escalated from simple incivility to public charges of impiety and atheism. Unpublished evidence suggests Morin wrote Cardinal Mazarin to expose Gassendi's heresies, he advised that Bernier be arrested, he urged that his enemies and their books be burned, and he maliciously predicted the death of Gassendi and Boulliau. Opinion varied. Gui Patin thought Morin "touched in the head", Pierre Bayle thought him a "fake savant" touched with genius. In any case, Morin broke unspoken rules, and his opponents destroyed his reputation. His methods, theories, and judgment were publicly condemned, his astrology was ridiculed, and his Latin was lampooned. Morin was attacked, avoided, and finally ignored.

Morin's often ugly career in astronomy was supported handsomely by astrology. Good evidence suggests he maintained strong ties with the court of Louis XIII, and by tradition, he was present at the birth of Louis XIV. Morin dedicated a number of publications to Richelieu and regularly cast horoscopes for king, queen, and the royal family. Mazarin awarded him an annual pension of 2,000 livres in 1645, and he reportedly earned 4,000 livres per year as astrologer, a princely sum. Following his death, Morin's *magnum opus*, the *Astrologia gallica* finally came to press in 1661, a large folio edition of some 850 pages. The most influential work of its kind, Morin extended principles pioneered by **Johann Müller** (Regiomontanus), boasting new astrological theories of elections and astrological houses. The volume appeared posthumously with assistance from the Queen of Poland, Louise-Marie de Gonzague, who supplied 2,000 thalers toward publication. The recommendation came from her secretary, Pierre Desnoyers, a major correspondent of Gilles Personne de Roberval and Boulliau. An advocate of both astrology and the New Science, Desnoyers, like many contemporaries, used the terms "astronomer" and "astrologer" interchangeably.

Morin was buried at Saint-Étienne-du-Mont. A decade later, in 1666, J.-B. Colbert proclaimed academics could no longer publish on astrology, and in 1682, by royal proclamation, astrological almanacs were forbidden in France. In the end, if Morin was the last great astrologer, he has yet to receive the historical attention he legitimately deserves.

Robert Alan Hatch

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Morley, Edward Williams

Born **Newark, New Jersey, USA, 29 January 1838**
Died **West Hartford, Connecticut, USA, 24 February 1923**

American chemist Edward Williams Morley is best known for his collaborative experiments with physicist **Albert Michelson**, which failed to detect an "ether-drift" effect on the speed of light measured in different directions relative to the Earth's motion. The negative result of the Michelson–Morley experiments may have helped inspire **Albert Einstein'**s special theory of relativity.

The son of a Congregational Minister, Morley received his BA (1860) and MA (1863) from his father's *alma mater*, Williams College, Williamstown, Massachusetts. There he studied with astronomer Albert Hopkins, who, during Morley's postgraduate year, guided his mounting of a transit instrument with which Morley then measured the college's latitude from observations of stars. In 1865, Morley read a paper about his results before the American Academy of Arts and Sciences and published it in their *Proceedings*. His work on these observations and their reduction has been credited with instilling in him the careful experimental nature that later led to his greatest successes. (Williams College's Morley Science Center was named for him in 2000.)

Intending to follow in his father's professional footsteps as well, Morley studied at Andover Theological Seminary, where he earned a license as a minister of the gospel in the Congregational Church (1861–1864). Morley spent the final months of the Civil War as a relief agent in the United States Sanitary Commission at Fort Monroe, Virginia, attending convalescing Union soldiers. He then returned to the seminary, where he studied until he was appointed teacher at South Berkshire Academy, Marlboro, Massachusetts.

In 1868 Morley moved to Ohio, where he briefly served as pastor of a Congregational Church in Twinsburg. Preaching did not agree with him, however, and he accepted an appointment to the faculty of Western Reserve College (1869), where he began a program of chemistry teaching and research, and where he served as chairman of the chemistry and natural history programs (1882–1906). Morley also taught chemistry and toxicology at the Cleveland Medical School (1873–1888). His interest in chemistry dated back to his boyhood, when he devoured not only popular works but also textbooks.

In 1887, he gave a series of lectures on Charles Darwin, natural selection, and evolution, which he preferred to call "development".

Over the course of his career, Morley focused on three significant problems. In the 1870s, he refined the techniques of gas analysis to demonstrate that colder air contained less oxygen than warmer air, thus proving the theory of Yale meteorologist **Elias Loomis** that attributed winter cold snaps to cold air falling from high altitudes.

In the 1880s, in order to evaluate the hypothesis of English chemist William Prout that all the elements were based on hydrogen, Morley developed procedures to determine the precise relative atomic weights of oxygen and hydrogen that eliminated impurities in the gases he tested, as well as every likely source of experimental error. Morley's determination in 1895 that the relative atomic weight of oxygen was 15.789 led him to conclude that Prout's hypothesis was invalid. In recognition of Morley's apparent resolution of a long-lived problem, Morley's colleagues elected him to the National Academy of Sciences (1897) and to the presidencies of the American Association for the Advancement of Science (1895–1896) and of the American Chemical Society (1899).

Yet Morley is best remembered for his work in the 1880s in collaboration with physicist A. A. Michelson of the Case School of Applied Science (later the Case Institute of Technology and then part of Case Western Reserve University), which failed to detect any "ether drift," taken as a given by all the contemporary wave theories of light. One way in which Morley improved Michelson's techniques was to eliminate sources of optical distortion by mounting his interferometer on a stone platform floating in mercury. Neither scientist, however, believed the null result of their efforts, and after Michelson's departure from Case in 1888, Morley continued to search for ether drift in collaboration with Michelson's successor, Dayton C. Miller.

Miller, who did not give up easily, reported a positive result at the December/January 1924–1925 meeting of the American Association for the Advancement of Science, for which he received a prize designated for the best paper of the meeting. Corecipient was **Edwin Hubble**, for his paper on the discovery of Cepheid variables in spiral nebulae, establishing their nature as separate galaxies, well outside the Milky Way.

Morley was married to Isabel Ashley Birdsall; they had no children. After Morley's retirement to West Hartford, Connecticut, in 1906, he stayed active by analyzing, in the chemistry laboratory at his home, geological samples collected in Indonesia by a neighbor. He traveled to England to accept the Davy Medal of the Royal Society in 1907 at the hands of Lord Rayleigh.

Naomi Pasachoff and *Jay M. Pasachoff*

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Morrison, Philip

Born **Somerville, New Jersey, USA, 7 November 1915**
Died **Cambridge, Massachusetts, USA, 22 April 2005**

American theoretical physicist and astrophysicist Philip Morrison is most often mentioned in connection with the 1959 suggestion, with Guiseppe Cocconi, that the most natural means of communication across interstellar distances would be radio waves, probably at a wavelength close to the 21 cm emitted by neutral atomic hydrogen gas.

Born to Moses and Tilly (*née* Rosenbloom) Morrison, Philip attended high school in Pittsburgh, Pennsylvania, and received a BS in physics in 1936 from the Carnegie Institute of Technology (now Carnegie Mellon). He earned a Ph.D. from the University of California (Berkeley), working in theoretical physics with **Robert Oppenheimer**, in 1940 and moved quickly through teaching positions at San Francisco State College (1940–1941) and the University of Illinois (1941–1942), where he was recruited by fellow Oppenheimer student Robert F. Christy for the Metallurgical Lab (atomic bomb project) at the University of Chicago.

Morrison worked initially on the design of the reactors to be built in Hanford, Washington, for producing plutonium from uranium. By 1944, as the Manhattan Project became more intense, he and many others moved to Los Alamos, New Mexico, site of the laboratory under Oppenheimer's direction. Morrison and Marshall Holloway were responsible for the final readiness and assembly of the plutonium bombs, both the one tested at the Trinity site on 13 July 1945 and the one dropped over Nagasaki on 9 August (for which he traveled to the Tinian Island take-off point). They and colleagues **Luis Alvarez** and Robert Serber wrote a letter, also to be dropped over Japan, which they hoped would reach a Japanese colleague and make clear the United States could deploy additional bombs if necessary. Morrison was also part of the assessment team sent to Japan soon after. The experience left him a life-long opponent of nuclear war, and indeed war in any form. He was for many years active in the Federation of American Scientists (serving as its chairman: 1972–1976), a group supporting peaceful uses of science.

After another year at Los Alamos (directing a plutonium reactor that he dubbed Clementine, because of its location "in a cavern, in a canyon . . .") Morrison took up an associate professorship at Cornell University. While there, he initially remained engaged in nuclear physics, coauthoring with **Hans Bethe** a classic text in the field. Morrison moved from Cornell to the Massachusetts Institute of Technology in 1965, officially retiring in 1986, but remaining actively engaged in physics research and teaching until shortly before his death.

Morrison's interests gradually shifted to astrophysics, initially the propagation of cosmic rays in the Solar System – he rightly associated the variation of the flux reaching Earth with solar effects – and their origins (which he associated with supernova remnants like the Crab Nebula and active galaxies). He wrote the first review article on γ-ray astrophysics, before the first source had been seen, predicting in 1958 that supernova remnants and active galaxies should be sources – but so should be interstellar space if sufficiently high-energy cosmic rays hit neutral gas making pions. All indeed are, though not such bright sources as Morrison had hoped.

It is worth noting that in 1959 when Cocconi and Morrison suggested the 21-cm search wavelength, it lay in an accessible region between the short-wave emission by the Earth's atmosphere and the longer wavelength emission by the Galaxy. The 3-K microwave background radiation had not yet been discovered. The suggestion led to the first modern search for radio signals from extraterrestrials, by Frank Drake in 1960.

Morrison guided a couple of dozen future physicists to and beyond Ph.D.s. Those who remained in cosmic-ray physics or astrophysics included Howard Laster, Kenneth Brecher, James Felten, Leo Sartori, Alberto Sadun, and Minas Kafatos.

Morrison and his students had for many years a remarkable record of bringing concepts of fundamental physics to bear on new astronomical results very quickly. This included:

(1) cooling of stellar remnants by neutrino emission (with Hong-Yee Chiu);
(2) calculation of X-ray production by various mechanisms (with James Felten), which permitted a calculation of how much hot gas would be required to produce the X-rays discovered to be coming from rich clusters of galaxies even as they were finishing the calculation – it turned out to be comparable with the total amount of mass needed to hold the clusters together gravitationally – the modern number is 30% of that;
(3) a fluorescent theory of supernova light emission (which shared some of the virtues with the radioactive decay mechanism that was ultimately adjudged correct);
(4) an analogy between active galaxies and pulsars as soon as the latter were discovered;
(5) a prediction of X-ray emission from the Crab Nebula and radio galaxies (later seen, though the mechanism is probably different);
(6) the suggestion with Brecher that the emission from γ-ray bursts must be beamed into a narrow cone;
(7) the association of a subset of active galaxies (including M 82) with star formation fueled by recent infall of new gas rather than with a central black hole; and
(8) a shadowing mechanism to account for the jet found to be sticking out of the edge of the Crab Nebula in the 1980s.

In spite of all these remarkable theoretical achievements, Morrison may well have made his greatest impact as a communicator of science. For decades, thousands of students in introductory astronomy courses have begun the term by watching a film he coproduced with his wife and Charles and Ray Eames, *Powers of Ten*, which illustrates the enormous range of length scales from subatomic physics to the cosmos. (The book version of 1980 was in collaboration with Phylis Morrison.) He was the narrator and guiding spirit of several educational television programs (*e. g.*, *Whisper from Space*, on the cosmic microwave background radiation, and *Ring of Truth*, a series dealing with how science works), and from 1968 to 1994 wrote virtually all of the book reviews that appeared in *Scientific American*, the December issue always featuring children's books, coreviewed by the Morrisons together. His first marriage, to Emily Morrison of Boston, ended in divorce in 1983, and his second wife and collaborator, Phylis Singer Morrison, died in 2002.

Morrison received honorary degrees from Case Western Reserve, Rutgers, and Denison universities, and medals and prizes from the American Physical Society, the American Chemical Society, and several other organizations. He was elected to the United States National Academy of Sciences.

It is probably useful in understanding Morrison's career to know that a childhood attack of polio left his legs considerably weakened, so that he was dependent on canes for getting around from midlife onward and later on a wheelchair.

Virginia Trimble

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Möschlin, Michael

➜ **Mästlin [Möstlin], Michael**

Mouchez, Ernest Amédée Barthélémy

Born **Madrid, Spain, 21 August 1821**
Died **Wissous near Paris, France, 25 June 1892**

Ernest Mouchez, a notable hydrographer and cartographer, directed a rejuvenation of the Paris Observatory and helped initiate the *International Carte du Ciel and Astrographic Catalogue* project. Mouchez's parents were French: His father, Jacques Barthélémy Mouchez, was a perfumer and wig maker to the spouses of the Spanish King Ferdinand VII. He was a widower when he married Mouchez's mother, Louise Cécile Bazin. Mouchez was sent to Paris for his studies, living with family friends. After attending the lycée in Paris and Versailles, he entered the École Navale.

After graduation, Mouchez served in the marine as an officer, rising to the rank of *contre-amiral* by 1878. During this period, he produced nearly 150 coastal maps of Asia, South America, and Algeria. (These last maps were the only ones available to Allied troops when they landed in Algeria during World War II.) Mouchez explored some 4,000 km along the Brazilian coast. Mouchez's work in hydrography and geographic astronomy contributed to the training of navigators, particularly for the determination of longitudes. He directed one of the voyages to observe the transit of Venus of 9 December 1874 at Saint Paul Island in the Indian Ocean, obtaining high-quality visual and photographic data.

In 1862, Mouchez married Carlota Finat (born: 1843), the second daughter of his half-sister Sophie, who was 7 years older than him. They had six children; their older daughter later married **Camille Guillaume Bigourdan**.

Mouchez succeeded **Urbain Le Verrier** as director of the Paris Observatory in 1878. In this position, he managed to liberate the astronomers from administration, opened the observatory to foreign exchanges and was a patron, along with Sir **David Gill** of the Cape of Good Hope Observatory, of the *Carte du Ciel*, inaugurated in 1887. This often-criticized enterprise of 18 observatories from all over the world found its value a century later: The accurate proper motions of almost one million stars from the *Carte du Ciel* catalog formed the first epoch for comparison with the "Brahe" catalog produced by the astrometric Hipparcos mission (1989–1992).

Under Mouchez's directorship, the observatory built the coudé equatorial from **Maurice Löwy**'s plans, with which the famous lunar map was obtained, along with **Henri Deslandre**'s spectroheliograph, which long provided standard references. In 1885, Mouchez formed a section on Astronomie physique, combining it with sections for Météorologie and Physique du Globe and placing them all under **Charles Wolf**. In 1890, he asked Deslandres to direct a section called Spectroscopie stellaire. This service, related to the new field of astrophysics, was discontinued when Deslandres moved to the Observatoire d'astronomie physique in Meudon, near Paris. Mouchez was also responsible of the first complete network of synchronous clocks in Paris, of the creation of the Paris Observatory museum, and the organization of regular visits for the public, still in existence. In 1884 he founded the first periodical devoted to astronomy in France called *Bulletin astronomique*. A few hours after presiding over a meeting of the Paris Observatory Council, Mouchez died suddenly at his cottage.

Mouchez was a remarkable organizer, having inherited a difficult situation from Le Verrier. Mouchez developed the Paris Observatory along the lines that **Friedrich Struve** had suggested to Le Verrier when the latter was thinking about reorganizing French astronomy. Mouchez was a member of the Bureau des longitudes from 1873 and of the Académie des sciences from 1875.

Solange Grillot

Selected Reference

Mouchez, Robert (1970). *Amiral Mouchez, Marin, Astronome et Soldat, 1821–1892*. Paris: Editions Cujas.

Moulton, Forest Ray

Born **Osceola County, Michigan, USA, 29 April 1872**
Died **Wilmette, Illinois, USA, 7 December 1952**

Forest Moulton is perhaps best remembered for his collaboration with **Thomas Chamberlin** on what became known as the Chamberlin–Moulton hypothesis.

Moulton was born in a log cabin built by his father Belah Moulton, a Civil War veteran, on the family's 160-acre homestead in Michigan. His mother, Mary (*née* Smith) Moulton, was impressed by rays of sunlight filtering through the surrounding forest; hence her son's name. Moulton was educated at home by his mother, next in a one-room school, and then at Albion College, from which he received his B.A. degree in 1894. He attended the University of Chicago as a graduate student in 1895, was appointed assistant in astronomy in 1896, received his Ph.D. in astronomy and mathematics in 1899, and then joined the university's faculty.

Moulton rose to full professor in the astronomy department. His field was celestial mechanics, including the three-body problem and its application to the motion of the Moon under the influence of the Earth and Sun. His 1902 text, *Introduction to Celestial Mechanics*, later revised in 1914, was widely utilized. More elementary texts were his *Introduction to Astronomy*, published in 1906, and *Descriptive Astronomy*, in 1912. With his colleagues at Chicago, Moulton developed a survey course and the accompanying text, *The Nature of the World and Man*, was published in 1926. It was reissued in 1937, and revised in 1939, as *The World and Man as Science Sees Them*. Moulton also wrote *Consider the Heavens*, a popular book, in 1935. Always interested in popularizing astronomy, Moulton acted as an informal advisor to Frederick Charles Leonard (1896–1960) and his Society for Practical Astronomy that enjoyed some success nationally in the period from 1910 to 1916. Leonard went on to found the astronomy department at the University of California at Los Angeles and established himself as an authority in meteoritics.

During World War I, Moulton was commissioned a major in the Army and placed in charge of the Ballistics Branch of the Army Ordnance Department at Aberdeen, Maryland. There, he developed new methods for calculating the trajectories of artillery projectiles. In 1926, he published *New Methods in Exterior Ballistics*. Also of a technical nature was Moulton's 1930 textbook, *Differential Equations*.

Moulton was a member of an interdisciplinary research team headed by Chamberlin, the chairman of the Geology Department at the University of Chicago. The team investigated mutual problems in geophysics and astronomy. Beginning in 1903, half of Moulton's salary was covered by Chamberlin's grant from the Carnegie Institution of Washington.

In his studies on the Earth's changing climate in the geological past, Chamberlin had begun to question the plausibility of **Pierre de Laplace**'s nebular hypothesis. Laplace had postulated that a hot fluid had cooled, condensed, and gradually shrunk to the present size of the Sun; rings of gas shed by the shrinking Sun had condensed into the planets of the Solar System. Chamberlin, however, realized that glaciation and salt deposits indicated a colder and more arid climate in the past, incompatible with the warm and moist conditions postulated by Laplace's theory.

More troubling was the fact that a majority of the Solar System's angular momentum resided in the orbits of the jovian planets, while its mass is heavily concentrated in the Sun—an unlikely occurrence within Laplace's nebular hypothesis. This unsymmetrical distribution of matter and angular momentum suggested to Chamberlin that the Solar System had been formed by the near-collision of a nebulous cloud and the proto-Sun. From his analysis of the dynamic considerations, Moulton concluded that the original solar nebula had perhaps been similar to a spiral nebula. Astronomers have since abandoned the Chamberlin–Moulton hypothesis, and have assumed an alternate version of the nebular hypothesis, despite its unsolved dynamical problems.

Moulton served as a private consultant to the directors of the Meteor Crater Exploration and Mining Company (1929/1930), organized by **Daniel Barringer**, and produced the most thorough analysis regarding the probable size, mass, and speed of the incoming projectile. His calculations cast serious doubt on the existence of a still-buried meteoric mass.

By the early 20th century, the calculation of orbits as practiced by Moulton had become somewhat obsolete. Observational astrophysics held much greater research promise than did theoretical astronomy. The booming business and stock market of the 1920s, in which Moulton's younger brothers were participating, offered an alluring alternative career, and Moulton resigned his position at the University of Chicago in 1926 to become director of the Utilities Power and Light Company in Chicago, where he remained until 1937. His company barely survived the Great Depression. Moulton also served as a trustee and director of concessions for Chicago's Century of Progress Exposition (1933/1934). He closed the concession's books in 1936 with a profit.

In the 1930s, after leaving the University of Chicago, Moulton retained his interest in popularizing astronomy. He conducted a weekly radio broadcast of interest to aspiring amateur astronomers that was heard throughout the midwestern United States. On each broadcast, Moulton offered copies of his books as a prize for the best weekly essay he received. More than a few of the recipients of these books went on to pursue careers in science and engineering, including Hugh M. Johnson who had a distinguished career as an X-ray astronomer.

Afterwards, Moulton undertook another major career move, serving as Permanent Secretary of the American Association for the Advancement of Science [AAAS] from 1937 to 1946, and as Administrative Secretary from 1946 to 1948. Under his direction, the Association doubled its membership and gained control of the Association's journal, *Science*, from the J. McKeen Cattel family. The archives of the AAAS contain records of Moulton's work there from 1937 to 1948.

Moulton was twice married and divorced: to Estelle Gillete, from 1897 to 1938, with whom he had four children; and to Alicia Pratt, from 1939 to 1951.

Norriss S. Hetherington

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Tropp, Henry S. (1974). "Moulton, Forest Ray." In *Dictionary of Scientific Biography*, edited by Charles Coulston Gillispie. Vol. 9, pp. 552–553. New York: Charles Scribner's Sons.

Mouton, Gabriel

Born **Lyon, France, 1618**
Died **Lyon, France, 28 September 1694**

Gabriel Mouton is most widely known for his work on a universal standard of length based on a "geometric foot" or one-thousandth of a *mille*. Mouton lived his whole life in Lyons. After obtaining a doctorate in theology he became, in 1646, a Vicar of Saint Paul's Church in that city. In spare time from his clerical duties he studied mathematics and astronomy.

Mouton's *mille* was proposed as a minute of longitude on the Earth's surface, a distance that eventually became known as a nautical mile. In 1670 Mouton developed a system of decimal divisions for his length standard. In order for this standard to be reproducible, Mouton proposed a pendulum of the standard length and measured the number of oscillations in 30 min. His value of 3959.2 oscillations was to be an easy way to verify that the pendulum was of proper length. A similar concept, but based on a pendulum with a period of 1 s in Paris, was later proposed as the basis for a universal system of measurement. However, the metric system as originally devised was not based on the length of a pendulum, but on a meter as one ten-millionth of the distance between the Earth's pole and Equator. Several of the principles used in Mouton's system were incorporated into the International System of Units [SI].

Mouton's astronomical accomplishments included determining the apparent diameter of the Sun at apogee. As an experimentalist, he constructed an astronomical pendulum. And, as a calculator, he was able to present a practical way to compute ordered tables of numbers such as logarithmic tables of trigonometric functions.

Mouton's work includes *Observationes diametrorum soles et lunae apparentium,* published in Lyons in 1670.

Donald W. Hillger

Selected Reference

Speziali, Pierre (1974). "Mouton, Gabriel." In *Dictionary of Scientific Biography,* edited by Charles Coulston Gillespie. Vol. 9, pp. 554–555. New York: Charles Scribner's Sons.

Mrkos, Antonín

Born **Střemchoví, Moravia, (Czech Republic), 27 January 1918**
Died **Prague, Czech Republic, 29 May 1996**

Antonín Mrkos is remembered as a discoverer of comets and minor planets, and for measuring the precise astronomical coordinates of these objects. The son of farmers, Mrkos studied at several secondary schools, including an ecclesiastical gymnasium, before entering the Technical University in Brno in 1938. His studies were interrupted by the onset of World War II, and during 1939–1943, he taught at primary schools at Nové Město and Ždárec in Moravia.

After a short stay in Austria, Mrkos took a position in 1945 under director **Antonin Bečvář** at the Skalnaté Pleso Observatory in Slovakia. There, Mrkos participated in the famous visual comet-hunting program using 25 × 100 Somet–Binar binoculars, as well as the cometary astrometric program with the 0.6-m reflector. Following his successful visual discovery of three comets (including 45P/Honda–Mrkos–Pajdušáková) in 1948, he made photographic recoveries of three periodic comets during 1949/1950. Mrkos was the principal observer with the 0.6-m reflector during 1946–1956.

Noting that the observatory's location (on the eastern slope of the second highest mountain, Lomnicky' Štít) in the High Tatras made it impossible to hunt for evening comets in the western sky, Mrkos decided to observe from the 2,634-m peak, to which he would regularly climb, shunning the more convenient cable cars. He also worked as a meteorologist for the weather station there. During a 4-year interval starting in early 1952, Mrkos visually discovered six more comets, including 18D/Perrine–Mrkos, an accidental rediscovery of a comet lost since the beginning of the century. With his private 0.5-m reflector, he recovered the intermediate-period comet 13P/Olbers in 1956.

Mrkos's most famous discovery, of C/1957 P1 (Mrkos) on 2 August 1957, was of one of the century's brightest comets, whose tail he detected while measuring the night sky glow at Lomnicky' Štít. Shortly afterwards, Mrkos traveled to Antarctica for 2 years with a Soviet expedition as part of the International Geophysical Year (1957/1958).

On his return to Slovakia, Mrkos made his 11th and final visual comet discovery in late 1959. During 1961–1963, he participated in another Soviet Antarctic expedition, working at Molodeznaya and Novolazarevskaya, after which he spent a year on the staff of the Geophysical Institute of the Czechoslovak Academy of Sciences in Prague, before taking a position (which he held until his retirement) in the astronomy department of Charles University. In addition, Mrkos was made director of the observatory at České Budéjovice in southern Bohemia, and this led to the establishment of a planetarium and of the new observatory he was to direct on Kleť Mountain.

Mrkos made the first photographic observations of comets with the 1-m reflector and 0.4-m Maksutov at Kleť Mountain in 1968, and the 1969 recovery of his comet 45P was an early success. The Kleť activity was extended to cover minor planets in 1977, and for many years it was the most regular contributor of data to the International Astronomical Union [IAU] Minor Planet Center. It was Mrkos's habit to spend 20 days each month at the observatory and 10 days in Prague reducing and typing up the observations prior to mailing.

Because of the dedication of Mrkos and assistants such as Růžena Petrovičová and Zdeňka Vávrová, at the time of his death, the program ranked as the sixth most successful ever launched for the discovery of minor planets that had been numbered. At that time, Mrkos was listed as the 11th most prolific discoverer. Two photographic discoveries of comets were credited to him at Kleť, bringing his lifetime total to 13. Among Mrkos's more interesting discoveries of minor planets is the near-earth object (5797) 1980 AA, later named "Bivoj." Mrkos was elected president of IAU Commission 6 during the triennium 1985–1988.

Following his retirement on 31 December 1991, Mrkos had hoped to continue his photographic astrometric work from a site closer to Prague. He located a small camera at an abandoned geodetic observatory near Ondřejov and planned to put it to use. An extended stay in the hospital in 1994/1995 delayed these plans, and on a subsequent visit to the remote site, he found that it had been vandalized. Particularly sad was the theft of his Somet–Binar binoculars, which had played a role in the visual discovery of 11 comets, and which Mrkos always had nearby when he was observing.

Brian G. Marsden

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Muʿādh

➔ **Ibn Muʿādh: Abū ʿAbd Allāh Muḥammad ibn Muʿādh al-Jayyānī**

Mukai, Gensho

Born **Hizen (Saga and Nagasaki Prefectures), Japan, 1609**
Died **Kyoto, Japan, 1677**

Gensho Mukai introduced Western astronomical ideas in Japan during the early Edo period; however, he retained a traditional Chinese cosmology. At age five, he moved to Nagasaki, where he learned astronomy under Kichiemon Hayashi and became a Confucian scholar as well as a physician. In 1658, Mukai moved to Kyoto, where he practiced medicine and remained until his death. Though little seems to have been written about his life, Mukai no doubt found his place among the intelligentsia of Confucian scholars in Kyoto in the early Edo Period (1603–1867). He is probably remembered as much for what was seen as his personification of Confucian ideals as he is for specific works that he wrote. Mukai's comparison of Eastern and Western concepts also seems to have had an influence not only on scholars who immediately followed him, but on Japanese society as a whole. He inspired his children, who exhibited notable intellect and creativity. Mukai's second son, Kyorai (1651–1704), was a poet and student of the famous *haiku* master, Basho Matsuo.

Mukai is probably best known in the context of Japanese science for introducing concepts of Western astronomy in the early Edo era, a time of growing isolation from the outside world. Under *Tokugawa* policies of seclusion, Nagasaki was the only link to the West, and indirect contact with European sources allowed some acquisition of western astronomical knowledge. This contact led to what has been termed *Nanban* astronomy, a scholarship that involved translation, commentary, and comparative evaluation of European and Chinese-derived epistemologies. As a part of such activity, Mukai completed a set of commentaries around

1650 titled *Kenkon Bensetsu* (Western cosmography with critical commentaries). This work was based on a translation by Christopher Ferreira, whose Japanese name was Chuan Sawano, of what no doubt were several European works, but most especially **Christoph Clavius**'s *In Sphaeram Ioannis de Sacro Bosco*, *Commentarius* (1607).

In Mukai's commentaries, for perhaps the first time in Japan, sphericity of the Earth was explicitly recognized. However, while Mukai was instrumental in introducing such concepts into Japan, his commentaries show a disdain if not outright antagonism at times for what he saw as contradictions to classic Chinese precepts such as the theory of five elements (wood, fire, earth, metal, and water). He never abandoned his beliefs in Neo-Confucian principles, and with his strong contrasts of European and Chinese models, was no doubt influential in making such principles central to intellectual thought in early Edo Japan.

Mukai saw the Earth as inextricably related to the sky, and the European view of nature was simply something he could not recognize. Although he did accept western astronomical knowledge as it related to enhance the classical concerns of traditional far-eastern astronomy, Mukai continually denounced physical theories based on the Aristotelian four elements. For example, whereas **Tycho Brahe** showed that trepidation was really a matter of observational error, Mukai dismissed the theory of north–south oscillation as an explanation for trepidation not because of observational discrepancies but because the idea of such oscillation did not fit within what he felt was the harmony of the five-elements theory.

Steven L. Renshaw and *Saori Ihara*

Selected References

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Nakayama, S. (1969). *A History of Japanese Astronomy: Chinese Background and Western Impact*. Boston: Harvard University Press. (This work remains the primary source in English for gaining a glimpse into the underlying methods and mathematics of astronomical development in Japan. Nakayama presents an extensive section on Mukai's commentaries, and with detailed explanations of both western and eastern precepts, gives a clear picture of the epistemological base from which most work in early Edo Japan was developed.)

——— (1978). "Japanese Scientific Thought." In *Dictionary of Scientific Biography,* edited by Charles Coulston Gillispie, Vol. 15 (Suppl. 1), pp. 728–758. New York: Charles Scribner's Sons. (Nakayama clarifies differences between epistemological views in Europe and Japan both before and during the era in which Mukai lived. He pays particular attention to differences in the way nature was conceived in the east and the west. In contrast to Needham, he argues that the ultimate goals of science in Europe and in China were indeed not the same. Such background helps the reader to understand the philosophical and social base from which Mukai and others of Nanban astronomy developed their comparisons.)

Sugimoto, M. and D. L. Swain (1989). *Science and Culture in Traditional Japan*. Tokyo: Charles E. Tuttle and Co. (This volume presents a comprehensive and scholarly view of scientific development in Edo Japan. Mukai's activities may be seen against the backdrop of a society whose leaders sought to increasingly isolate the country from outside influences. Sugimoto and Swain pay special attention to contrasts between traditional Chinese derived epistemologies and those seeping into Japan indirectly from the West.)

Muler, Nicolaus

Born **Brugge, (Belgium), 1564**
Died **Groningen, the Netherlands, 1630**

Nicolaus Mulerius, a professor of medicine and mathematics at the University of Groningen, edited the 1617 (Amsterdam) version of **Nicolaus Copernicus's** *De Revolutionibus.* In it, he included extensive notes and a thesaurus of observations to supplement the text of the two earlier editions.

Alternate name

Mulerius

Selected Reference

Swerdlow, N. M. and O. Neugebauer (1984). *Mathematical Astronomy in Copernicus's De Revolutionibus*. 2 pts. New York: Springer-Verlag.

Mulerius

➜ **Muler, Nicolaus**

Müller, Edith Alice

Born **Madrid, Spain, 5 February 1918**
Died **Spain, 24 July 1995**

With **Leo Goldberg** and **Lawrence Aller**, Spanish astrophysicist Edith Müller determined the abundances of chemical elements in the Sun. She served as general secretary of the International Astronomical Union and was the first woman to do so. She was based in Switzerland for many years.

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Blaauw, Adriaan (1996). "Edith Alice Müller, 1918–1995." *Bulletin of the American Astronomical Society* 28: 1457–1458.

Müller, Johann

Born **Königsberg, (Bavaria, Germany), 6 June 1436**
Died **Rome, (Italy), 8 July 1476**

Johann Müller (Regiomontanus) published valuable astronomical ephemerides and mathematical texts and devised new instruments and methods of observation. He was to 15th-century astronomy as **Nicolaus Copernicus** and **Tycho Brahe** were to 16th-century astronomy.

Johann Müller himself used the scholarly name "Johannes de monte regio" or similar names. Though he evidently never used it himself, since the 16th century he has been known as Regiomontanus, from the Latin for Königsberg (King's mountain).

Young Johann was a child prodigy and was sent off to the University of Leipzig at the age of 11. Three years later, he visited Vienna and stayed on as a student under **Georg Peurbach** at the university there, receiving his bachelor's degree in 1452 (at age 15); upon receiving his master's degree in 1457, Regiomontanus was appointed to the University of Vienna's faculty. He was tremendously knowledgeable about ancient, medieval, and contemporary scholarly works, and he knew Latin and Greek.

A visit by Cardinal Bessarion to Vienna in 1460 led to Regiomontanus traveling to Rome and many other places in Europe, before settling in Nuremberg in 1471, where he set up a print shop to publish scholarly works with technical diagrams. As was typical of the astronomers of his day, Regiomontanus was very much both an astrologer and an astronomer, though he seemed to spend more time in his later years on astronomical science and mathematics than on astrology. He was also a religious man, and his personal trademark sign was a cross on a hill with a background of stars. Regiomontanus was supposedly called by the Pope to Rome in 1475 or 1476, where he died of unknown causes (though the plague has been suggested as a possibility), suddenly terminating an increasingly productive career in revolutionizing astronomy.

Johann Gutenberg had published the first printed astronomical calendar in 1448, and while at Leipzig, young Regiomontanus was drawn toward checking the accuracy of that calendar, finding errors between the predicted positions of the planets and their true locations in the sky. This led him on an intense astronomical career to build an improved astronomy that would forever hold him as the foremost astronomer of 15th-century Europe. During his lifetime, Regiomontanus created much impact by traveling to visit astronomers elsewhere, by corresponding with astronomers in technical discussions, by seeking out classical writings on astronomy and encouraging publication of new translations of them, and by writing and publishing his own widely consulted works on astronomy. Among those with whom Regiomontanus dealt was **Paolo Toscanelli** of Florence, who made perhaps the most accurate positional observations of comets in the 15th century. One of the problems that Regiomontanus eagerly attacked was that of a comet's position, size, and distance, and his "Sixteen Problems" regarding these unknown quantities became a much-cited work after **Johann Schöner**'s publication of the manuscript in 1531, upon the appearance of Halley's comet, (IP/Halley)

Regiomontanus' *Ephemerides* were heavily used in Europe because they were seen as authoritative in predicting eclipses, phases of the Moon, positions of the Sun, Moon, and planets, and church calendar information.One of the reasons that ephemerides such as these were so popular was the strong European adherence to astrology in that era. Copernicus and Christopher Columbus both annotated their own copies of *Ephemerides*, and it has been argued that both Columbus and **Amerigo Vespucci** must have used Regiomontanus' almanacs on their voyages overseas; Columbus likely used his copy for impressing the American natives in Jamaica by successfully predicting the lunar eclipse of 14 September 1494. Copernicus was heavily influenced by Regiomontanus' *Epitome* and *Ephemerides* in his writing of *De revolutionibus*.

Regiomontanus wrote an impressive book, *De triangulus omnimodis* (On triangles), a treatise on plane and spherical trigonometry that was first published in 1533. This book was much used by European astronomers in the 16th and 17th centuries to determine celestial positions. Regiomontanus wrote this organized text on geometry and trigonometry specifically for use by astronomers, realizing that astronomers needed these mathematical tools to advance their knowledge of the motions of celestial objects. Even though his treatise was built on the work of ancient and medieval mathematicians, Regiomontanus added his own theorems and employed algebraic techniques for solving geometric problems; he utilized his geometric procedures in his other astronomical work, as can be seen in his treatise on comets.

Regiomontanus was also interested in making astronomical instruments for improved astronomical observations – one of the essential ingredients for building a better astronomy. Making better clocks seems to have been a part of these endeavors, as he attempted to construct a planetary clock. Had Regiomontanus lived to old age, his impact on astronomy would doubtless have been much greater, given his talents and enthusiasm. He envisaged publishing many more books on astronomy – translations into Latin of historical works and also many of his own new works on the subject.

Numerous manuscripts and letters written by Regiomontanus are extant in various libraries, attesting to a prolific career of correspondence and writing on topics astronomical and mathematical. His instruments, books, and papers passed to **Bernard Walther** of Nuremberg at the death of Regiomontanus. Walther kept these estate items to himself, unwilling to share them, until his death in 1504, when they began to be scattered through various sales. Schöner purchased much of the estate material on astronomy belonging to Peurbach, Regiomontanus, and Walther around 1522, eventually publishing much of the unpublished materialof the three men. Even the famous artist **Albrecht Dürer** eventually purchased Regiomontanus' copy of Euclid's *Elements* at auction.

Daniel W. E. Green

Alternate name

Regiomontanus

Selected References

Regiomontanus and G. Peurbach. (1496). *Epytoma Joanis De Monte regio In almagestum ptolomei*. Venice: Johannes Hamman. (Translation from Greek to Latin of a condensed version of Ptolemy's *Almagest*, with commentary, by Peurbach and Regiomontanus. Their commentary included some mention of where Ptolemy had erred, which caught Copernicus's attention and was thus influential.)

Hughes, Barnabus (trans.) (1967). *Regiomontanus on Triangles*. Madison: University of Wisconsin Press. (Recent English translation of Regiomontanus's monumental work on geometry and trigonometry.)

Pedersen, Olaf (1978). "The Decline and Fall of the *Theorica Planetarum*: Renaissance Astronomy and The Art of Printing." In *Science and History: Studies in Honor of Edward Rosen*, edited by Erna Hilfstein *et al.*, pp. 157–185. *Studia Copernicana*, Vol. 16, 161ff. Wroclaw: Ossolineum, Polish Academy of Sciences Press. (Discussion of Regiomontanus' printing philosophy and his impressions of Peurbach's work, with some translation of Regiomontanus' passages into English.)

Regiomontanus. (1474). *Ephemerides*. Nuremberg: Johann Muller of Königsberg.

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Snell, W. (1618). *Coeli & siderum in eo errantium Observationes Hassiacae Lantgravii … Quibus accesserunt Ioannis Regiomontani & Bernardi Walteri Observationes Noribergiacae*. Leiden: Justum Colsterum. (Contains astronomical observations of Regiomontanus and his colleagues, though with some typographical errors.)

Steele, John M. and F. Richard Stephenson (1998). "Eclipse Observations Made by Regiomontanus and Walther." *Journal for the History of Astronomy* 29: 331–344. (Translation of eclipse observations with technical assessment.)

Thorndike, Lynn (1934, 1941). *A History of Magic and Experimental Science*. Vol. 4 (1934): p440ff; Vol. 5 (1941): 332ff. New York: Columbia University Press. (Extensive discussions of Regiomontanus and his impact on astronomy in late-medieval and early-modern times.)

Zinner, Ernst (1964). *Geschichte und Bibliographie der astronomischen Literatur in Deutschland zur Zeit der Renaissance*. Stuttgart: Anton Hiersemann, p. 7ff. (List of all known publications and reprintings of Regiomontanus' tracts, together with some interesting text putting Regiomontanus into context for his time period.)

———(1990). *Regiomontanus: His Life and Work*, translated by Ezra Brown. Amsterdam: Elsevier Science Publications. (The most extensive biography of Regiomontanus, recently translated from German to English.)

Müller, Karl

Born **1866**
Died **22 October 1942**

With **Mary Blagg**, Viennese selenographer Karl Müller wrote the definitive reference *Named Lunar Formations* (1935), sponsored and adopted by International Astronomical Union Commission 17.

A formation on the Moon is named for him.

Selected Reference

Chong, S. M., Albert Lim, and P. S. Ang (2002). *Photographic Atlas of the Moon*. Cambridge University Press.

Müller, Karl Hermann Gustav

Born **Schweidnitz (Swidnica, Poland), 7 May 1851**
Died **probably Potsdam, Germany, 7 July 1925**

Karl Müller's career, devoted to photographic photometry, produced valuable contributions in the form of catalogs of both photometric data and of variable stars.

Educated at Leipzig University and Berlin University, Müller worked briefly for **Arthur von Auwers** and then assisted **Hermann Vogel** at the Astrophysical Observatory at Potsdam from its beginning in 1877. During 1917–1921 he served as that institution's Director.

From early in his career, Müller pursued the study of terrestrial lines in the solar spectrum. His investigation of the Sun's brightness over its disk resulted in several expeditions to climb high mountains (including Tenerife at age 59). Müller's planetary and asteroid work recorded changes in brightness as a function of phase. He began in 1886, assisted by **Paul Kempf**, the construction of the *Potsdam Durchmusterung*, giving visual magnitudes and colors of all stars in the northern sky down to magnitude 7.5. (With **Ernst Hartwig**, Müller compiled a catalog of more than 1,600 variable stars from 1916 to 1921.)

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Muñjāla

Flourished **Deccan, (India), possibly 900**

Muñjāla was the author of a remarkable work, the *Laghumānasa*, which is an abridged version of a larger work called *Bṛhanmānasa*. Very little is known about the life of Muñjāla, except that he was a *brāhmaṇa* belonging to the *Bhāradvājagotra*, and that he lived in Deccan.

The *Laghumānasa* was very popular among the astronomers from Kerala, and it is mentioned by **Bīrūnī**. **Parameśvara** wrote a commentary on it, and quotations from it are found in the works of Bhāskaracārya and Munīśvara.

The *Laghumānasa* appears to be the first siddhāntic text to treat the precession of the equinoxes. Muñjāla gives the number of "ayana" revolutions to be 199,669 in a kalpa, and the "ayanāṃśa" to be 6° 54′ in 932 and the year of zero "ayanāṃśa" as 522. Muñjāla was the first Indian astronomer to introduce corrections to the Moon's equation that account for what today is called evection. Muñjāla anticipates Bhāskaracārya in understanding that the sine and cosine are related in a way that we would express today by saying the derivative of a sine function is a cosine function.

Narahari Achar

Alternate name

Mañjula

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Muñoz, Jerónimo

Born **Valencia, Spain, *circa* 1520**
Died **Salamanca, Spain, 1592**

Jerónimo Muñoz, a leading Spanish astronomer and geographer of the 16th century, observed the supernova of 1572 (SN B Cas) and speculated upon its cosmological significance. Muñoz began his studies at the University of Valencia, from which he received his Bachelor of Arts degree in 1537. He continued studies at other European centers and received a Master's degree. Two of his principal instructors were **Oronce Finé** and **Gemma Frisius**. Being an expert Hebraist, Muñoz for some time was professor of Hebrew at the University of Ancon. He returned to Valencia sometime before 1556; in 1563, he was appointed to the chair of the Hebrew Department in Valencian General Studies. In 1565, Muñoz was also named head of the Mathematics Department. In 1578, he accepted the chair of mathematics at the University of Salamanca. Muñoz was also awarded the chair of that institution's Hebrew Department.

In Valencia and Salamanca, Muñoz taught arithmetic, geometry, and trigonometry, geometrical optics, astronomy and its applications, astronomical instruments, cartography, geography, and astrology. Although Muñoz did not publish many works, his personal manuscripts, and students' copies of notes and texts prepared for his classes, are preserved at the libraries of Salamanca, Barcelona, Madrid, Munich, the Vatican, Naples, and Copenhagen.

In Spain, Muñoz enjoyed a wide reputation as mathematician, astronomer, geographer, Hellenist, and Hebraist. His fame at other places in Europe was due primarily to his published work on the supernova of 1572 entitled *Libro del Nuevo Cometa* (Book of the new comet) (Valencià, 1573). This account of the "comet" was prepared at the request of Phillip II. It was then translated and reprinted in French (1574). Muñoz corresponded about the "comet" with several astronomers, including the Viennese doctor and mathematician Bartholomaeus Reisacherus, and the imperial doctor of Bohemia, **Tadeá Hájek z Hájku** (Hagaecius). From the latter, but especially through the work of **Cornelius Gemma** (*De Naturae Divinis Characterismis*, 1575), which included an extensive account of Muñoz's observations, his own data and conclusions eventually reached **Tycho Brahe**. Brahe then dedicated a chapter with commentary in his *Astronomiae Instauratae Progymnasmata* (1602) to the work of Muñoz.

As an observational astronomer, Muñoz achieved the highest precision in determining stellar positions. He should likewise be counted among the astronomers who exposed the cosmological implications of the "comet," recognizing that maintenance of the Aristotelian dogma regarding an incorruptible sky (violated by the supernova's appearance) was untenable. Although Muñoz called the object a comet, he recognized that it looked more like a star than a comet. His reason for classifying it as a comet had much to do with his desire to find natural causes for the phenomenon, without calling upon divine omnipotence (*potentia dei absoluta*), which other astronomers and mathematicians such as Frisius, **Thomas Digges**, Hagaecius, or Brahe himself did invoke.

Muñoz's work on the supernova of 1572 must be placed in the context of his ambitious scheme to revise Aristotelian cosmology and Ptolemaic astronomy. This can best be seen by Muñoz's comments about the second book of **Pliny**'s *Natural History* and in his translation (with numerous additions) of the *Commentary on the mathematical composition of Ptolemy* by **Theon of Alexandria**. Within his comments on Pliny, read at the University of Valencia in 1568, Muñoz presented some cosmological ideas similar to the Stoic tradition. He rejected the idea of the sphere of fire and considered the cosmos to be a continuous medium that became progressively more rarified as one moved away from the center (the Earth) and eventually trailed off into an immense vacuum. Using various arguments, Muñoz also rejected the idea of crystalline spheres and thought that the planets moved through the cosmic medium upon their own natures.

Muñoz clearly showed that the discipline of astronomy could successfully address questions from natural philosophy. On the other hand, his astronomical observations and comparisons to available planetary predictions, gleaned from **Ptolemy** to **Nicolaus Copernicus** and **Erasmus Reinhold**, led him to doubt the viability of Ptolemy's parameters, those of subsequent astronomers, and his own contemporaries. But the reform in astronomy required a radical transformation in the realm of instrumentation and a systematic program of observations – things that remained out of reach for a modest university professor. As for cosmology, Muñoz never accepted the Copernican system. Instead, he proposed a cosmology consisting of a fluid heaven and a theory of planetary movements resulting from different sources. That cosmology's qualitative features were described without the use of mathematical astronomy.

Muñoz was a successful geographer and cartographer; these were subjects to which he further applied his mathematical knowledge. He determined precise geographic coordinates (*e. g.,* latitudes) of numerous places on the Iberian Peninsula, of which he then drew a map. He applied geodetic methods of triangulation, which he learned from his teacher Frisius and which he taught in his own classes with practical examples. The oldest surviving map of the Kingdom of Valencia, appearing in Abraham Ortelio's atlas, *Theatrum Orbis Terrarum* (1570), was prepared from Muñoz's data.

Muñoz trained a large number of students including prominent military engineers and treaty writers such as Diego de Alava, university professors, and several leading cosmographers from the late 16th to the early 17th centuries who were in service to the Spanish monarchy.

Victor Navarro-Brotóns
Translated by: *David Valls-Gabard*

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N

Naburianu [Naburianus, Nabû-ri-man-nu]

Flourished **Probably 5th century BCE**

Naburianu was a Babylonian astronomer whose name is mentioned by **Pliny** in his first-century text, *The Natural History*. In 1923, he was identified with an astronomer by the name of Nabû-?-man-nu by the cuneiform scholar Paul Schnabel. The name occurs in the colophon of a lunar ephemeris of System A from Babylon for the year 263 of the Seleucid era, or 48/47 BCE. Schnabel reconstructed the name to Nabû-ri-man-nu and concluded that he was responsible for discovering the System A method of computation of the Moon's position, dating him to around 427 BCE. Schnabel's claim has been effectively challenged by **Otto Neugebauer**, who points out that the inclusion of Nabû-ri-man-nu's name on the ephemeris is hardly evidence that he invented the system of computation on which it is based.

Nicholas Campion

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Najm al-Dīn al-Miṣrī: Najm al-Dīn Abū ʿAbd Allāh Muḥammad ibn Muḥammad ibn Ibrāhīm al-Miṣrī

Flourished **Cairo, (Egypt), *circa* 1300–1350**

Little is known of the life of the Cairene applied astronomer Najm al-Dīn al-Miṣrī, who was a contemporary of **Mizzī**. Several works, though, help document his scientific activities. Following are some of them:

1. A concise treatise on spherical astronomy entitled *Treatise on the Universal Operations [of Timekeeping] by Calculation*.
2. A short treatise on approximate methods of timekeeping.
3. A huge set of tables covering 419 folios, extant in two codices, which form the first and second halves of a single copy that was later split. In the main table, the time since the rising of the Sun or a star is tabulated in terms of three arguments. With nearly 415,000 entries, this is the single largest mathematical table ever compiled before the late 19th century.
4. An anonymous treatise, which can be attributed to Najm al-Dīn al-Miṣrī, gives detailed instructions on how to use these as universal auxiliary tables for solving all problems of spherical trigonometry for any terrestrial latitude. (The tables and the commentary have been analyzed in Charette, 1998.)
5. The previous item forms the prologue of an illustrated treatise – also anonymous – on the construction of over 100 different astronomical instruments (astrolabes, quadrants, sundials, *etc.*). This work has been recently shown to be by Najm al-Dīn al-Miṣrī (Charette, 2003). The text and its accompanying illustrations represent one of the richest and most astounding medieval sources on the topic of astronomical instrumentation.

Although Najm al-Dīn's writings suggest that he was not a first-rate astronomer, especially on the theoretical level, his intuitive and practical, "hands-on" approach to timekeeping (*mīqāt*) and instrumentation did yield original results.

François Charette

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Napier, John

Born **Merchiston Castle near Edinburgh, Scotland, 1550**
Died **Edinburgh, Scotland, 4 April 1617**

John Napier spent much time in devising methods of facilitating and shortening astronomical calculations.

Napier was educated at Saint Andrews University and traveled on the Continent in his youth. Settling down at his family seat of Merchiston, he devoted his attention to many subjects, writing on theology and politics, and investigating various branches of science. His invention of logarithms with base e was announced in 1614. The invention was of great assistance to **Johannes Kepler**, and made possible the rapid development of astronomy in the 17th century. He also created the mathematical tool known as Napier's bones. (Local legend considered Napier to be a wizard.)

Napier was married, widowed, and remarried. His descendants still hold the title of Lord Napier.

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Nasawī: Abū al-Ḥasan ʿAlī ibn Aḥmad al-Nasawī

Born **Rayy, (Iran), 1002/1003**

Nasawī was an astronomer and mathematician whose name indicates that his family was originally from Nasā, a town in ancient Khurāsān that is in present-day Turkmenistan. He spent most of his life in his birthplace. In the introduction to his book, *Bāz-nāma* (On caring for falcons), Nasawī states that he served in the army, had been in the service of the kings, and trained birds of prey for 60 years, since age eight. Bayhaqī remarks that Nasawī lived until the age of 100. However, the date of his death is unclear.

Nasawī's disciple Shahmardān Rāzī, as well as **Naṣīr al-Dīn al-Ṭūsī**, refer to Nasawī as *al-ustādh al-mukhtaṣṣ* (distinguished teacher), probably due to his expertise in mathematics and astronomy. The famous Iranian poet Nāṣir-i Khusraw (1003–1088) writes in his *Safar-nāma* that he met Nasawī in Simnān (Iran) in 1046, where the latter was teaching Euclid's *Elements*, medicine, and arithmetic. Nasawī also quoted from discussions he had had with **Ibn Sīnā**, which led Nāṣir-i Khusraw to conclude that Nasawī had been a disciple of Ibn Sīnā. It has been claimed that Nasawī was also a disciple of **Kūshyār ibn Labbān**, but Nasawī would have been too young when Kūshyār died.

Nasawī wrote several astronomical works, only one of which is extant. *Kitāb al-lāmiʿ fī amthilat al-Zīj al-jāmiʿ* (Illustrative examples of [the 85 chapters] of [Kūshyār's] *Zīj-i jāmiʿ*) is also called *Risāla fī maʿrifat al-taqwīm wa-'l-asṭurlāb* (A treatise on the almanac and the astrolabe).

Only a few of the tables from *al-Zīj al-Fākhir* (The glorious astronomical tables) have survived following the Leiden manuscript of Kūshyār's *Zīj-i jāmiʿ*. These tables indicate that the values used for the planetary mean motions are extracted from **Battānī**'s *zīj*, confirming remarks in *al-Zīj al-mumtaḥan al-ʿarabī*, a recension of **Muḥammad ibn Abī Bakr al-Farisī**'s *Zīj* preserved in Cambridge.

Ikhtiṣār ṣuwar al-kawākib (Summary of the constellations) is dedicated to al-Murtaḍā, the Shiʿite leader from Rayy. This nonextant work was a summary of **ʿAbd al-Raḥmān al-Ṣūfī**'s book on the constellations.

Nasawī was also a noted mathematician and wrote works on arithmetic, geometry, and spherics. Among his works are his *al-Muqniʿ fī al-ḥisāb al-Hindī*, a treatise on Indian arithmetic whose purpose was, among other things, to be useful for both businessmen and astronomers. Chapter 4 of *al-Muqniʿ* deals specifically with sexagesimal reckoning used in Islamic astronomy. *Al-Tajrīd fī uṣūl al-handasa* (An abstract of Euclid's *Elements*) was composed for those who wanted to learn geometry in order to be able to understand **Ptolemy**'s *Almagest*.

Nasawī also wrote works on philosophy, pharmacology, and medicine.

Hamid-Reza Giahi Yazdi

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Nasmyth, James Hall

Born **Edinburgh, Scotland, 19 August 1808**
Died **South Kensington, (London), England, 7 May 1890**

James Nasmyth advocated volcanic origin of the craters and other lunar features and devised a novel arrangement for the optical path of a Cassegrain telescope, yielding what is now identified as the Nasmyth focus in reflecting telescopes. The marriage of the painter Alexander Nasmyth and Barbara (*née* Foulis) Nasmyth yielded four sons and seven daughters, of which James was the youngest. On 16 June 1840, Nasmyth married Anne Hartop, daughter of the manager of the ironworks in Barnsley near Manchester, England. There were apparently no children from this marriage.

James Nasmyth showed exceptional mechanical aptitude and took an early interest in foundries and chemical laboratories. In his late teens, he made model steam engines and constructed, under a commission from the Scottish Society of Arts, a primitive automobile that he called a "steam road-carriage." After working as an associate of the noted machine toolmaker and engineer Henry Maudslay, Nasmyth established his own factory at Patricroft near Manchester. There he manufactured machine tools, hydraulic punches, pile drivers, and steam hammers, the latter an invention for which he bitterly disputed priority. The enterprise proved so profitable that Nasmyth was able to retire to the town of Penshurst in Kent at the age of 48.

Encouraged by his close friend, the Liverpool brewer and accomplished amateur astronomer **William Lassell**, Nasmyth became a telescope maker. At Patricroft, he used a succession of Newtonian reflectors, culminating in a 13-in. instrument. Ever inventive and attempting to improve objects that attracted his attention, Nasmyth introduced both an improved mirror grinding and polishing machine, and an improved formulation of speculum metal used to cast mirrors. After moving to Kent, Nasmyth erected a 20-in. telescope of innovative design. By introducing a planar tertiary mirror inclined at an angle of 45° between the primary and secondary mirrors of a Cassegrain reflector, the necessity of perforating the primary mirror was obviated, and a more accessible eyepiece position was provided in a hollowed-out trunnion bearing for the tube mounting. Neglected for decades, this "bent Cassegrain" or "Nasmyth" configuration became widely adopted in the 20th century on many large professional instruments featuring heavy spectrographs and large modern alt-azimuth mountings.

Always keenly interested in the Moon, Nasmyth became one of the first to contribute to **William Birt**'s committee to map the Moon. Unlike Birt, who looked for evidence of ongoing changes in the lunar surface, Nasmyth focused on the origins of the features that he saw scattered over its crowded surface. A self-taught amateur, he enlisted a more learned collaborator for his work: **John Carpenter**, a computer and later assistant astronomer at the Royal Greenwich Observatory. In their book on the Moon, an influential work about the lunar surface, Nasmyth and Carpenter accepted that lunar craters had been formed by volcanic action. But they did not attempt to gloss over the fundamental difference of form between terrestrial craters and their lunar counterparts. Terrestrial volcanic craters consist of a caldera or hollow atop a mountain, but the interior bowls of lunar craters are almost invariably depressed below the level of the surrounding surface. And yet despite the apparent differences in form, Nasmyth and Carpenter nevertheless affirmed **John Herschel**'s view that lunar craters manifest "the true volcanic character in its highest perfection."

Nasmyth and Carpenter endorsed a version of **Pierre de Laplace**'s cosmogony, in which particles of diffused primordial matter condensed and aggregated into a spherical planetary body consisting of a solid shell encompassing a molten core. Consistent with his empirical approach, Nasmyth did not take the formation of such a solid shell on faith but confirmed at an iron-works that cold slag floated on molten slag. During an 1865 visit to Vesuvius, then undergoing an eruption, he and Carpenter observed a lake of molten lava on the plateau or bottom of the crater on which vast cakes of the same lava that had solidified were floating.

Nasmyth applied these principles to the evolution of the Moon. He theorized that cooling from the outside inward, the Moon's encasing outer shell would cause pressures to build up in the still-molten interior until a portion of the molten interior burst through the shell "with more or less violence according to the circumstances." As each successive shell cooled and contracted in the attempt to accommodate itself to the core beneath it, the skin would crease into alternating ridges and depressions, "like a long-kept shriveled apple." Nasmyth and Carpenter saw everywhere on the surface of the Moon evidence of this general process.

The main problem in understanding the origin of the lunar features remained their sheer size relative to those of the Earth. The Vesuvian crater was less than 2 miles across, tiny by lunar standards. Even the largest terrestrial volcanic craters measure only some 15 miles across, yet lunar craters such as Tycho and Copernicus, with diameters of 50 and 56 miles respectively, were not even the largest specimens of their kind.

Nasmyth and Carpenter, proposed a "fountain model" solution: The reduced surface gravity of the Moon, combined with the negligible resistance of its thin atmosphere, would cause lunar volcanoes to eject a pyramid of matter around an orifice. Their theory required the ejected material to fall symmetrically in order to build up the crater walls and produce a ring structure. Later, the vent hole would fill with lava to produce the crater floor or give rise to the central peaks found in many of the lunar formations. As the lunar crust grew thicker and more rigid, and the reserves of lava dwindled, these last gasps of the Moon's dying internal activity that created the central peaks found in so many craters were, according to Nasmyth and Carpenter, evidence that such internal activity had ceased long ago.

Nasmyth's and Carpenter's theory was widely accepted and overshadowed other theories of the origin of the craters until well into the 20th century. The impression made by their book was greatly enhanced by the inclusion of 24 photographs of exquisite plaster-of-Paris models of lunar formations. Taken under oblique lighting, these plates made the book almost as much a work of art as a piece of scientific literature. The models were very deceptive, however, as they consistently depicted the Moon's surface as far more jagged than it is in reality. These rugged landscapes and sharp, craggy peaks provided evocative illustrations in popular books on the Moon for decades.

Nasmyth also made many observations of the Sun. His depiction of the granulation of the solar photosphere as a series of luminous filaments that he called "willow-leaf structure" remained in vogue for several decades but was ultimately proven to be an illusion.

Thomas A. Dobbins

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Nasṭūlus: Muḥammad ibn ˁAbd Allāh

Flourished **10th century**

Nasṭūlus is credited with constructing two astrolabes. The first, dated 927/928, is considered the oldest surviving astrolabe (though not the first ever constructed). This elegant instrument is preserved in the Kuwait Museum of Islamic Art. It has a single plate (for latitudes 33° and 36°) on the back of which are four quadrant scales and a shadow scale. The throne bears the inscription, "Made by Nasṭūlus (or Basṭūlus) in the year 315." The second astrolabe, of which only the *mater* is still extant, bears no date but was probably constructed around 312 hijra (925). It is preserved in the Museum of Islamic Art in Cairo; the inscription "Made by Nasṭūlus" appears on the throne. It contains the earliest and only geographical list to appear on an instrument before *circa* 1100. The purpose of the gazetteer on the *mater* is evidently to show which plates should be used in different cities. Most of the latitudes included are derived from **Khwārizmī**'s geographical table, although the remainder may have been taken from other early sources such as **Battānī** (*circa* 910). Although no original plate has survived, the instrument has various Mamluk additions, dated 1314.

We know almost nothing about this astronomer, and even his name remains in doubt. Some historians have interpreted the manuscripts to refer to someone with a Greek name, perhaps Βατύλος/βαθύλος or Απόστολος. However, it is unclear whether he is a Muslim or Christian. King claims that he was a Muslim based on the testimony of the 10th-century astronomer **Sijzī**, who states that a certain Muḥammad ibn ˁAbd Allāh (clearly a Muslim name), known as Nasṭūlus, was the first person to design the astrolabe with a crab-shaped rete. Sijzī adds that Nasṭūlus also invented the hours drawn on the face of the alidade and the operation with the azimuth on the back of the astrolabe. This statement was later repeated by **Bīrūnī** in his *Istīˁāb*, in which he adds that Nasṭūlus was one of the people who worked on instruments for determining eclipses. On the other hand, M. Hinds suggests Nasṭūlus might refer to the Christian sect of the Nestorians, and Kunitzsch points out that the form Nasṭūrus was attested in 10th-century Egypt, and was used by Christian men. Nasṭūlus would then be just another form of Nasṭūrus.

Mònica Rius

Alternate name

Basṭūlus

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Nayrīzī: Abū al-ˁAbbās al-Faḍl ibn Ḥātim al-Nayrīzī

Flourished **Baghdad, (Iraq), last half of the 9th century**

Nayrīzī is reputed to have been among the best mathematicians and astronomers of his day, though not much biographical information is known. In astronomy, his best-known work, a commentary on the *Almagest* of **Ptolemy**, is no longer extant. This must have been one of the earliest commentaries to be written in Arabic, because the *Almagest* had been first translated into Arabic only a century earlier. He is also credited with the composition of two *zīj*es (astronomical tables used for predicting planetary motions). The longer was said, by the bio-bibliographer Ibn al-Qifṭī, to have been based on the *Sindhind*, an Indian classic in astronomy. The shorter was, presumably, based upon the *Almagest*. These works were cited by several astronomers from the ˁAbbāsid period, although they are no longer extant. Three shorter, more specialized treatises survive: (1) on the spherical astrolabe; (2) on finding the *qibla* direction (the direction toward Mecca, toward which pious Muslims pray five times a day); and (3) on constructing hour lines in a hemispherical sundial. **Ibn Yūnus**, in his own *zīj*, criticized some elements of Nayrīzī's astronomical work while praising him as a renowned mathematician.

Gregg DeYoung

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Neison, Edmund

➜ **Nevill [Neville], Edmund Neison**

Nemicus, Tadeá

➜ **Hájek z Hájku, Tadeá**

Nernst, Walther Hermann

Born **Briesen, Wąbrźezno, Poland, 25 June 1864**
Died **Muskau, (Sachsen), Germany, 18 November 1941**

After elucidating the third law of thermodynamics, for which he won the 1920 Nobel Prize in Chemistry, physicist Walther Nernst worried about the consequences of the second law for the fate of the Universe. Entropy seemed to require an eventual "heat death" to everything. **Victor Hess**'s discovery of cosmic rays gave Nernst hope that perhaps there was a constant source of new matter and energy at large, so that the Universe could go on – much as it is – indefinitely. Nernst called this a steady-state cosmology.

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Neugebauer, Otto E.

Born **Innsbruck, (Austria), 26 May 1899**
Died **Princeton, New Jersey, USA, 19 February 1990**

Austrian–German–American mathematician and historian of mathematical astronomy Otto Neugebauer meticulously demonstrated the technical content of ancient mathematical astronomy and the ingenuity in abstract thinking of ancient mathematicians and astronomers.

Otto Neugebauer's father, Rudolph Neugebauer, was a railroad engineer. The Protestant family moved to Graz, Austria, when Otto was still young. There Otto attended the Akademisches Gymnasium, studying mathematics, mechanics, and technical drawing, in addition to the Greek and Latin required by the curriculum. In 1917 he enlisted in the Austrian army, ostensibly to avoid taking the Greek examination to receive his graduation certificate. Neugebauer became a lieutenant of artillery, spending the remainder of the war as a forward observer on the Italian front.

In 1919 after his discharge, Neugebauer entered the University of Graz to follow a course in electrical engineering and physics, transferring to the University of Munich in 1921. There he attended lectures by Arnold Sommerfeld and Arthur Rosenthal. After the death of his parents and as the result of Austrian hyperinflation, Neugebauer lost his entire inheritance and suffered a difficult winter, but in 1922 he changed the focus of his education, moving to the Mathematisches Institut at the University of Göttingen, where he studied under Richard Courant, the new director of the institute, and with Edmund Landau and Emmy Noether. By 1923 Neugebauer became an assistant at the institute, and in 1924, special assistant to Courant, and was put in charge of the library. During 1924 he spent time at the University of Copenhagen with Harald Bohr, with whom he published his only paper in pure mathematics.

During this time Neugebauer studied Egyptian mathematics, publishing a seminal document on the *Rhind Papyrus*, a late Egyptian mathematical document.

In 1927 Neugebauer received his *venia legendi* for the history of mathematics, and became a *Privatdozent* (lecturer). He soon married Grete Bruck, a fellow student, also a mathematician: Their two children, Margo and Gerry (a distinguished infrared astronomer), were born in 1929 and 1932, respectively. The following year Neugebauer traveled to Leningrad, Russia, to work with Wilhelm Struve in preparing the *Moscow Papyrus*, an important text in Egyptian mathematics, for publication. In 1929 Neugebauer founded a Springer series devoted to the history of mathematical sciences, astronomy, and physics, the *Quellen und Studien zur Geschichte der Mathematik, Astronomie und Physik*. Under his editorship, its focus would be primarily on Egyptian mathematics.

Starting in 1927, Neugebauer had learned Akkadian in an investigation of Babylonian mathematics, which eventually enabled him to establish the origin of the sexagesimal system, and collect a substantial corpus of texts later published as *Mathematische Keilschrift-Texte*, in several volumes. This corpus demonstrates the richness of Babylonian mathematics.

Neugebauer was founding editor of the review journal *Zentralblatt für Mathematik und ihre Grenzgebiete* and a Springer series of short monographs on current mathematics. But when Adolph Hitler became chancellor of Germany, Neugebauer was removed from his job at the Courant Institut for presumed political unreliability. Obtaining a professorship at the University of Copenhagen starting in 1934, he prepared a series of lectures on Egyptian and Babylonian mathematics, and planned a volume on Greek mathematics.

In his 1928 review of *The Venus Tablets of Ammizaduga* by Stephen Langdon *et al*., Neugebauer demolished the earlier chronology of the Old Babylonian dynasty. In a paper a decade later, he similarly cast doubt on the use of the Sothic cycle for establishing the origin of the Egyptian calendar. Neugebauer became intensely interested in astronomical cuneiform texts, which were primarily ephemerides in the form of arithmetic functions for computing lunar and planetary phenomena. He developed a method using linear Diophantine equations to check these functions, with the result that many previously unrelated cuneiform fragments were joined and dated. This work showed that some functions ran continuously for hundreds of years, and provided the basis for much significant work to follow. After publishing some of his results in 1938, Neugebauer had his work interrupted by difficulties with Springer and his editorship on the *Zentralblatt*, from whose board he resigned in December. Neugebauer was immediately offered a position at Brown University in the United States, which he readily accepted, moving to Providence, Rhode Island, and founding *Mathematical Reviews* in 1939. He shortly afterward applied for American citizenship.

At Brown University, Neugebauer quickly published several papers on ancient astronomy and mathematics, later reprinted in his book *Astronomy and History* (1983). His most famous work is *The Exact Sciences in Antiquity*, a survey of Egyptian mathematics and astronomy, and their relation to Hellenistic science and its descendents. Neugebauer's treatment of the subject emphasizes the transmission of ideas as they were developed, with many cultures adding to the corpus of understanding and observations of astronomical phenomena.

With his collaborator Abraham Sachs, Neugebauer published all the known Assyrian astronomical texts as *Astronomical Cuneiform Texts* (1955), most dating from the last three centuries BCE. In his preface he commended the spirits of the ancient scribes of Enu ma-Anu-Enlil, who "by their untiring efforts … built the foundations for the understanding of the laws of nature … they also provided hours of peace for those who attempted to decode their lines of thought two thousand years later."

Neugebauer published several analyses of Egyptian astronomical documents, tomb ceilings, coffin lids, zodiacs, and papyri, collecting these works in the three-volume work *Egyptian Astronomical Texts* (1960–1969). His later *History of Ancient Mathematical Astronomy* (1975) indicated, however, that the Egyptian contribution to mathematical astronomy was minimal.

Along with the chief librarian at Brown University, a classicist and papyrologist, Neugebauer published *Greek Horoscopes* (1959), the standard work on the subject, containing an introduction to the methods of Greek astrology. He planned a history of mathematical astronomy from antiquity to **Johannes Kepler**, and published many ancient texts from several languages, including Greek, Latin, Indian, Arabic, and Ethiopic. Neugebauer's *History of Ancient Mathematical Astronomy* established the history of ancient astronomy on a new foundation and demonstrated the continuity of the science from ancient times to the present. The material included planetary and lunar theory, astrological sources, the works of **Ptolemy** and their derivatives, chronology, astronomy, and his own methods that had proved so useful. In later publications he dealt with astronomy in the Middle Ages, Byzantine sources, and analysis of **Nicolaus Copernicus**'s *De revolutionibus*, Ethiopic astronomy, chronology, and the calculations of the ecclesiastical calendar, with an analysis of the primitive astronomical section of the *Book of Enoch*.

Neugebauer became professor of the history of mathematics at Brown University, and was named the Florence Pirce Grant University Professor at Brown University in 1960. After his retirement, he moved to the Institute for Advanced Study at Princeton University, where he spent the remainder of his life. Some of the work Neugebauer completed during his last years was published posthumously.

Neugebauer received honorary doctorates from Saint Andrews University (Scotland), Princeton University, and Brown University; was elected to membership in academies of science and the arts of Denmark, Belgium, Austria, Britain, Ireland, France, and the United States; received the Balzan Prize (1986), the Franklin Medal (American Philosophical Society, 1987), and awards from the History of Science Society, the Mathematical Association of America, and the American Council of Learned Societies; and in 1967, became the only historian of science ever awarded the Russell Lectureship of the American Astronomical Society. His approach to the history of mathematical astronomy continues in the work of many influential scholars.

Katherine Haramundanis

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Neumann, Carl Gottfried

Born **Königsberg (Kaliningrad), Russia, 7 May 1832**
Died **Leipzig, Germany, 27 March 1925**

Carl Neumann developed new techniques in mathematical physics that have found diverse applications in dynamical astronomy and other research areas. Neumann was born into a noted academic family; his aunt was married to the astronomer and mathematician **Friedrich Bessel**. His father, Franz Ernst Neumann, a professor of physics at Königsberg University, contributed to advancements in the wave theory of light and the mechanical theory of heat. Neumann attended Königsberg University and completed his doctorate in 1855. After post-doctoral work at the University of Halle, Neumann became a *Privatdozent* (lecturer) there until his promotion to assistant professor in 1863, when he accepted a position at the University of Basle. After 2 years, he moved to the University of Tübingen, before settling at the University of Leipzig in 1869. One of Neumann's prominent students was **Hugo von Seeliger**. He remained there until his retirement (1911). In 1864, Neumann married Hermine Mathilde Elise Kloss.

Neumann's initial work on the Galilean–Newtonian theory of mechanics influenced mathematicians, physicists, and astronomers of the time, many of whom studied under him. His chief contributions were in mathematical physics: the application of mathematical techniques to the study of mechanics and electrodynamics, especially harmonic analysis ("potential functions") used in the solutions to partial differential equations (*e. g.*, Laplace's equation). These tools have since become standard for the mathematical modeling of physical processes involving electricity, electromagnetism, fluid dynamics, and gravitation.

Today, Neumann's methods and techniques are found in a surprising array of applications, including structural analysis, contact problems with friction (*e. g.*, the Dirichlet–Neumann algorithm), domain decomposition algorithms for the treatment of elastic body problems, spectral properties of the Neumann Laplacian involving stars and comets, and even the global potential functions used in programming the paths of robots.

Neumann was a cofounding editor (with Alfred Clebsch) of the prestigious and influential journal *Mathematische Annalen*, led subsequently by **Felix Klein** and David Hilbert.

Daniel Kolak

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Nevill [Neville], Edmund Neison

Born **Beverley, (Humberside), England, 27 August 1849**
Died **Eastbourne, (East Sussex), England, 14 January 1940**

Edmund Nevill, regarded for a short time as the preeminent selenographer in Britain, provided a firm basis for later lunar studies. Nevill was educated at Harrow and New College, Oxford. During the Franco–Prussian war of 1870/1871, he joined the French army, serving on the staff of marshal Ney. After the war, Nevill followed a journalistic career and for a time was parliamentary reporter for *The Standard* (London), as well as a theater critic. He worked alone and without financial sponsorship, and produced a contribution of outstanding importance in its day. He wrote under the pseudonym "Edmund Neison" in the conviction that the holder of an ancient name should not make a career in science. Nevill played an excellent game of tennis and was a golf enthusiast. His wife, Mabel (*née* Grant), whom he married in 1894 and who was South Africa's tennis champion for 11 years, survived him by several years.

Following an early interest in astronomy, Nevill became a fellow of the Royal Astronomical Society in 1873 at the age of 24. Using the classic work of **Wilhelm Beer** and **Johann von Mädler**, Nevill initiated a serious study of the Moon with a 6-in. refractor and a 9.5-in. With–Browning reflector from his residence in Hampstead, London. His voluminous book on the Moon was an important text; though based largely on the work of Beer and Mädler and in places merely a translation of *Der Mond*, it skillfully integrated all contemporary data to produce one of the most useful lunar reference works available in the English language and established Nevill's place in the history of astronomy.

In 1873 and 1874, Nevill argued for the existence of an appreciable lunar atmosphere and endorsed the idea that the Moon's craters represented the results of "vast volcanic convulsions," although he felt under obligation to discuss, at some length, Beer and Mädler's view that the surface of the Moon showed an "entire dissimilarity to that of the Earth." This was the general impression furnished by the small telescope that Beer and Mädler had employed, but with resemblances more compelling following the work of **Jean Chacornac**, Nevill found that closer examination with powerful instrument revealed far greater terrestrial analogy in the structures of the Moon than otherwise appears even possible. He reported that while a general analogy is often traceable between terrestrial volcanic regions and the more disturbed portions of the lunar surface, through powerful telescopes the larger craters appeared "less and less like volcanic orifices or craters." Indeed, their enclosing walls lost their regularity of outline and appeared instead as confused masses of mountains broken by valleys, ravines, and depressions, an irregularly broken surface.

Although Nevill accepted the probability of minor changes on the Moon and was convinced that the change reported by the German selenographer **Johann Schmidt** in 1867 within the small crater Linné on the plain of the Mare Serenitatis had been real, he departed from the conventional view that the alteration signified a volcanic upheaval, suggesting that it represented the comparative whimper of a landslide. However, Nevill expressed doubt when the German astronomer **Hermann Klein** reported in 1877 that Hyginus N was of recent origin.

Nevill had earlier written about the possibility of a lunar atmosphere (1873) and in greater detail on that subject in *Popular Science Review* in October 1874. Nevill was unafraid to voice his opinions. He was a founding member of the short-lived Selenographical Society (1878–1882), and served as its secretary until his career took an unexpected turn in 1882.

Though chiefly known for his work on lunar morphology, Nevill had a very strong interest in lunar theory and in 1877 confirmed the reality of an inequality in the longitude of the Moon, produced by the action of Jupiter, an effect that had been detected by Newcomb in 1876. The value obtained by Nevill for this term is close to that currently accepted. That same year he published a memoir containing the theoretical foundations of a complete analytical development of lunar theory, essentially a simplification of earlier treatments.

As part of the preparations to observe the transit of Venus in December 1882, a long-discussed plan to set up an observatory in Durban, South Africa was finally activated through the efforts of Harry Escombe and **David Gill**. Nevill was offered and accepted the post of government astronomer at Natal, and sailed for Durban arriving on 27 November 1882, a few days before the transit. He encountered many difficulties, but the weather at least was in his favor and the phenomenon was successfully observed. It was an auspicious start; Nevill conceived many plans, including observations to perfect the tables of lunar motion, and the establishment of the observatory as a meteorological center. He also became government chemist and official assayer for Natal, acting sometimes as pathologist in instances of suspected poisoning. However, promises of official funding were unfulfilled, and things became more difficult until, in 1911, the observatory was closed.

Nevill gave up his scientific career and returned to England. On retirement he settled at Eastbourne on the South Coast where he remained agile and unimpaired in mind and body unto the last, indulging his varied interests, especially chemistry. In the 1870s he had, with C. T. Kingzett, pressed for the setting up of a body to represent the profession of chemistry. At a meeting in the rooms of the Chemical Society (of which he was a fellow) on 26 April 1876, a committee was appointed as a first step toward the foundation of the Institute of Chemistry. Nevill was an original member of its council, serving from 1877 to 1880, and for some time was honorary corresponding secretary for the Institute of Natal Province. In 1935 he was awarded the Medal of the Royal Chemical Society.

Nevill was inactive, astronomically speaking, for almost three decades after returning to the United Kingdom from Africa, and he was assumed to have long since died. Twice, he refused the invitation to become a Fellow of the Royal Society, though in 1908 he was finally persuaded to accept. Nevill also declined the presidency of the Royal Chemical Society, and though a fellow, seldom, if ever, attended meetings of the Royal Astronomical Society. He researched Babylonian history, wrote several novels (but never submitted them for publication), and in 1886 published a popular outline of astronomy.

Richard Baum and *Thomas A. Dobbins*

Alternate name

Neison, Edmund

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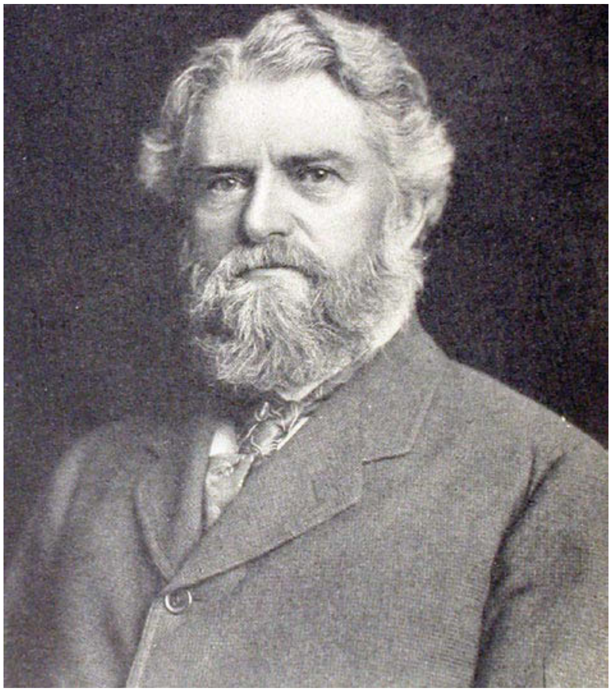
Newcomb, Simon

Born **Wallace, Nova Scotia, (Canada), 12 March 1835**
Died **Washington, District of Columbia, USA, 11 July 1909**

The commanding figure of United States astronomy in the 19th century, Simon Newcomb systematized and brought unparalleled precision to our knowledge of the Solar System.

The oldest of seven siblings born to parents of New England extraction, Newcomb grew up in the British colony of Nova Scotia, later part of Canada. His father, John Burton Newcomb, was an itinerant village schoolmaster; his mother, Emily Prince, was the daughter of a New Brunswick magistrate.

Largely home-schooled or self-taught, Newcomb spent his childhood in various parts of Nova Scotia and Prince Edward Island. Around age 15, he grew estranged from his mother's Calvinist beliefs and never really settled on an alternate faith. Apprenticed at 16 to a quack doctor, he ran away in 1853 and joined his father



in the United States, gaining a schoolteacher's position at Massey's Cross Roads, Maryland.

Through relentless study of authors ranging from Euclid to **Isaac Newton**, Newcomb acquired an increasingly profound understanding of mathematics. He submitted his first paper to **Joseph Henry**, secretary of the Smithsonian Institution, and was encouraged to persevere. Having moved closer to Washington, DC, Newcomb started to draw on the riches of the Smithsonian library. Henry soon recommended the United States Coast Survey as a suitable outlet for his talents. Referred in turn to the Nautical Almanac Office, then in Cambridge, Massachusetts, he arrived in December 1856 and became an astronomical computer. Newcomb simultaneously enrolled in Harvard's Lawrence Scientific School, studying mathematics under **Benjamin Peirce** and obtaining his B.Sc. in 1858. He never looked back.

When the Civil War began in 1861, Newcomb was appointed to the United States Naval Observatory in Washington, replacing staff that had departed to join the Confederacy. In 1863, he wedded Mary Caroline Hassler, granddaughter of the founder of the Coast Survey, Swiss-born Ferdinand Hassler. They would have three daughters, Anita, Emily, and Anna. In 1864, Newcomb was naturalized as a United States citizen.

In 1875, Newcomb was offered the directorship of Harvard College Observatory but turned it down, just as he declined the opportunities to replace Henry at the Smithsonian Institution or to head the Coast and Geodetic Survey. Instead, he accepted the superintendency of the Nautical Almanac Office in 1877. By then, he was accumulating honors: the Gold Medal of the Royal Astronomical Society, the Huygens Gold Medal of the Dutch Academy of Science, memberships in European scientific societies, and honorary degrees.

Newcomb served as president of the American Association for the Advancement of Science [AAAS] in 1877. He shared responsibility for the 1874 and 1882 American observations of the transits of Venus. In 1876, he lectured at the newly created Johns Hopkins University in Baltimore, Maryland, turning his course into a best-selling book, *Popular Astronomy* (1878). Newcomb was formally named a professor of mathematics and astronomy at Johns Hopkins University in 1884.

In 1890, the Royal Society of London awarded Newcomb the Copley Medal, and the Paris Académie des sciences chose him in 1895 to replace **Hermann von Helmholtz** as a foreign associate. In 1898, Newcomb received the Astronomical Society of the Pacific's first Catherine Wolfe Bruce Medal, and became, in 1899, the first president of the Astronomical and Astrophysical Society of America, later the American Astronomical Society. In 1907, France made him a Commander of the Légion d'honneur. Elevated by the United States to the rank of rear admiral, he was buried with full military honors in Arlington National Cemetery.

Newcomb's first important scientific result was his demonstration that the asteroids could not have originated, as **Heinrich Olbers** had suggested in 1803, from the fragmenting of a single planet. The work's 1862 publication in the German research journal *Astronomische Nachrichten* attracted notice abroad.

By then, Newcomb was already mastering the practical side of astronomy at the Naval Observatory, standardizing procedures, and tracking down systematic errors in stellar position catalogs. He took part in eclipse expeditions of 1860, 1869, 1870, and 1878, and played a key role in procuring for the observatory the nation's then largest telescope, a 26-in. refractor, inaugurated in 1873.

On the theoretical side, Newcomb analyzed the orbits of the Solar System's then-known outermost two planets, Uranus and Neptune, and published greatly improved tables for both by 1874. But he won fame by tackling a subject that was starting to exercise astronomers, namely, the gap between the observed motion of the Moon and theoretical attempts to represent it. By 1869, **Peter Hansen**'s 1857 lunar theory, based on data from 1750 to 1855, was clearly deviating from observations.

Newcomb realized that he could recover precise positional data from the Paris Observatory's records of lunar occultations, which yielded results stretching back to 1675. His reduction of the occultations was finished by 1888, although Newcomb was unable to complete the entire analysis before his retirement. With the inclusion of eclipses reported by **Ptolemy**, the observations spanned some 2,600 years. In a summary of his results, Newcomb identified a fluctuation that could not be attributed to gravity. It was later established as arising from the variable rotation (mostly slowing) of the Earth, as Newcomb had suspected.

Ensconced at the Nautical Almanac Office, Newcomb initiated a comprehensive redetermination of the constants of dynamical astronomy, from the best data obtained since 1750 by the world's observatories, in order to prepare new tables and formulas for the construction of ephemerides. One of the investigation's fruits was an improved value for the anomalous advance of Mercury's perihelion. (He favored some slight deviation from Newtonian gravity over the hypothetical intra–Mercurian planet Vulcan as the explanation.) With the help of several skilled mathematicians, Newcomb essentially completed this monumental endeavor by 1894.

Newcomb's retirement in 1897 did not end his career. In 1899, he published new tables of Uranus and Neptune, superseding his own earlier effort. A modest congressional stipend and later Carnegie grants from 1903 onward, enabled him to remain active in the international movement to standardize astronomical constants and basic data. Newcomb produced new catalogs of reference stars and rederived the principal constant of precession. Many of his numerical values endured until the advent of satellites and electronic computers led to superior determinations.

In other work, Newcomb refined the calculation of Jupiter's mass. In 1892, he deduced the approximate rigidity of the Earth. In the early 1900s he made the first quantative estimate of the background light of the night sky (equivalent approximately to one fifth magnitude star per square degree) and showed that the zodiacal light actually extends almost to the north ecliptic pole.

Newcomb also sought to better determine the distance to the Sun. Since the transits of Venus had proven disappointing, he measured anew the speed of light in order to find the distance directly from Earth's orbital velocity. His value for the speed of light was confirmed by the 1882 experiments of **Albert Michelson**. Though uncertainty persisted, Magnus Nyrén's 1883 constant of aberration yielded a result that turned out to be substantially correct.

Among the most distinguished scientists of his time, Newcomb was a celebrated figure who wrote astronomy textbooks and popularizations, works on economics, various opinion pieces (including a notorious refutation of the possibility of flying machines), and even some fiction.

First and foremost, Newcomb raised 19th-century positional astronomy to a pitch of perfection widely admired by his peers. Upon taking charge of the *Nautical Almanac*, he proposed changes in the ephemerides that were partially adopted by 1882. Results of his work were used by United States almanac makers from 1901 to 1960. Internationally, Newcomb's constants, theories, and tables for the Sun and the inner planets were not wholly superseded until 1984, so that his influence on astronomical ephemerides spans over a century. His contributions have been overshadowed by the more glamorous field of astrophysics, but Newcomb's precise determination of Mercury's perihelion advance lent inescapable significance to **Albert Einstein**'s derivation of the same within general relativity.

Most of Newcomb's works are found in the *Astronomical Papers Prepared for the Use of the American Ephemeris and Nautical Almanac*, 1879–1913, and in his 1895 volume, *The Elements of the Four Inner Planets and the Fundamental Constants of Astronomy*. Over 40 of his books and papers are available as microforms from the Canadian Institute for Historical Microreproductions. Newcomb's personal papers are held at the United States Library of Congress. He is widely held to have been the prototype of Walt Whitman's "Learned Astronomer."

Jean-Louis Trudel

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Newton, Hubert Anson

Born **Sherborne, New York, USA, 19 March 1830**
Died **New Haven, Connecticut, USA, 12 August 1896**

Hubert Newton, who made some of the first rigorous studies of meteor orbits and their distribution in interplanetary space, was among the first to recognize meteors, fireballs, and meteorites as the same objects differing only in mass and velocity.

Newton was the fifth son of 11 children born to educators William and Lois (*née* Butler) Newton. At age three, he witnessed the spectacular Leonid meteor storm; his later prediction concerning its maximum activity in 1866 brought him fame. Newton was schooled locally until 1846 when he entered Yale College. He showed great aptitude for mathematics and the physical sciences, and won election to the Phi Beta Kappa Society. On 14 April 1850, Newton married Anna C. Stiles, with whom he parented two daughters.

Following his graduation in 1850, Newton studied mathematics privately for several years before accepting the position of mathematics tutor at Yale College in 1853. He was elected professor of mathematics in 1855, a position he held until his death. Newton also became director of the university's observatory. Under his charge, a research program on meteor photography was developed, principally carried out by **William Elkin**.

In the early 1860s, Newton conducted a survey to find accounts of outbursts similar to the 1833 Leonid storm, then regarded as an unpredictable phenomenon. He correctly deduced that the Perseids are distributed around the Sun in an elliptically shaped ring, though his calculated orbit differed significantly from today's accepted orbit, first determined by **Giovanni Schiaparelli** in 1866.

In an important 1864 paper, Newton coined the term "meteoroid" to describe interplanetary debris and suggested that the orbits of meteoroids closely resemble those of some comets. His review of 13 historical observations of the Leonids revealed cyclical outbursts with a period of about 33 years, and that the shower had been active since at least 902. Newton successfully predicted a Leonid meteor storm for 1866. He concluded that the Earth passes through the densest part of the meteor swarm during these times, strong evidence that the meteors are not uniformly distributed throughout their orbiting ring. Newton calculated that the Leonid meteors are spread out over 40 million miles along their orbit, with a stream thickness exceeding 100,000 miles.

Newton found five orbits consistent with the data, noting that analysis of the stream's nodal regression would single out one of them. In 1867, **John Couch Adams** showed that Leonid meteoroids move along highly elliptical orbits, with periods of 33.25 years and aphelia as distant as Uranus. Calculations by Carl A. Peters, Schiaparelli, **Urbain Le Verrier**, and **Theodor von Oppolzer** showed that Leonid meteoroids follow orbits nearly identical to that of a comet observed in 1866 (now identified as comet 55P/Tempel–Tuttle). This was the second occasion for evidence linking a comet with a meteoroid stream, following Schiaparelli's 1866 connection of the Perseids with comet 109P/Swift–Tuttle.

Further evidence that meteoroids are cometary decay products came from Newton's study of the Bielid (also known as Andromedid) meteors, which had produced impressive displays in 1798, 1830, 1838, 1841, and 1847; the irregular intervals defied simple explanation. Newton observed over 1,000 Bielids per hour on 24 November 1872, inspiring him to investigate the swarm named for their connection to comet 3D/1826 (Biela). After discovering the parent comet's close encounters with Jupiter in 1772 and 1841, Newton determined the planet's perturbing effect on the meteoroids' orbits and its contribution to the comet's breakup into meteoric fragments. Newton later demonstrated how Jupiter and Saturn could "capture" passing comets, perturbing the meteoroids coming from these comets from parabolic to elliptical orbits.

Newton's studies of the Bielids led to his investigation of how meteoroids burn up in the Earth's atmosphere and on how they might produce meteorites on the ground. He developed a sizeable collection of meteorites that he later donated to Yale's Peabody Museum of Natural History. Newton noticed that many specimens showed a smoothed side, which he interpreted as the "leading side" of the meteorite that bore the brunt of heating and melting by its passage through the atmosphere, and a rougher "trailing" side, which he believed escaped the worst of the ablative process. Studying meteor trails, Newton suggested that irregularly shaped meteoroids would experience differential air resistance, leading to a trail that would straighten after leading parts melted and smoothed and would diverge when asymmetric parts lead.

Newton confirmed this theory after studying a remarkable photograph, made by amateur astronomer John Lewis, of a fireball that appeared over Ansonia, Connecticut, on 13 January 1893. Newton measured Lewis's photographic plate to determine the distances from the fireball's trail to several bright stars that appeared on the plate. From the varying brightness of the fireball's trail, Newton concluded that it rotated more rapidly during the latter portions of its flight through the atmosphere – the first mention in the scientific literature of meteoroid rotation. From his study of the Ansonia fireball, Newton urged that photography of meteor trails would allow their orbits to be determined with considerably greater accuracy.

Newton's investigations turned to the origin and distribution of comets. In an 1878 paper, he argued that the distribution of cometary aphelia and inclinations were consistent with the interstellar-capture theory proposed by **Pierre de Laplace**. While this idea for the origin of comets is no longer held to be true, Newton importantly showed for the first time that long-period comets could be captured into short-period orbits through the gravitational perturbations of the planet Jupiter.

Newton's interests in meteoric phenomena were wide-ranging. He analyzed the nebular hypotheses of **Immanuel Kant** and Laplace, each of whom had attempted to explain the Solar System's origin through the contraction of a primordial cloud. Applying these theories to the origin of comets, Newton thought that Laplace's version of the nebular hypothesis accounted for most of the long-period comets, with orbital inclinations greater than 30°, while Kant's version, which argued that the comets were closely associated with the planets and should show orbits of smaller inclinations, better explained the short-period comets. Newton also wrote several papers and gave many lectures on the history of meteors and meteorites, including the worship of meteorites by ancient cultures and American Indians. He served as an expert witness in an Iowa dispute over meteorite ownership. Newton aggressively advocated adoption of the metric system of weights and measures, and lobbied for the 1866 enactment legalizing the metric system in North America.

Upon his retirement in 1886, Newton addressed the American Association for the Advancement of Science on the relationship between meteorites and shooting stars (meteors). He also speculated on the processes responsible for the origin and formation of meteorites; this talk included the first-ever discussion of cooling rates, a tool used by modern meteoriticists to analyze the origins and evolutionary histories of primordial Solar System material. Newton died on the date of the Perseid meteors' maximum activity, having witnessed a fine display of these meteors just the night before.

Newton served as president of the American Association for the Advancement of Science during 1885 and 1886. In 1872, he was elected foreign associate of the Royal Astronomical Society, and in 1892 was elected as a foreign member of the Royal Society of London. Newton was awarded the J. Lawrence Smith Gold Medal of the National Academy of Sciences for his work on meteors in 1888. He was a founding member of the National Academy of Sciences. The University of Michigan awarded Newton an honorary Doctor of Laws degree in 1868.

Martin Beech

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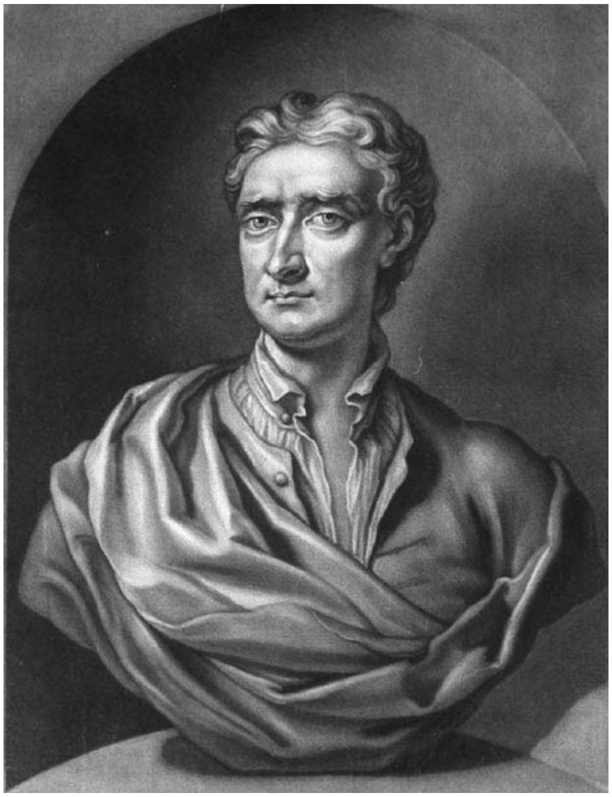
Newton, Isaac

Born **Grantham, Lincolnshire, England, 25 December 1642**
Died **London, England, 20 March 1727**



Sir Isaac Newton was born as a fatherless child on Christmas day. He was then given by his mother Hannah at 3 years to be reared by his grandmother. The young Isaac did not receive undue parental nurturing. There were stories of how his youthful inventions alarmed the inhabitants of Grantham village, such as a night-flying kite that carried a lit candle. The sundial he constructed as a youth is now owned by the Royal Society of London.

After a grammar school education in Grantham, Newton entered Trinity College, Cambridge, in June 1661 and was chosen as a scholar in 1664. In 1669, the college elected him a fellow and the university, through the influence of **Isaac Barrow**, the incumbent, appointed him Lucasian Professor of Geometry.

In December 1671 Newton presented a 2-in.-diameter reflecting telescope – the first ever constructed – to the Royal Society, which led to his election as a fellow. The telescope had a short lifetime because its mirror surface clouded over in a fortnight: It took over a century for nontarnishing reflectors to be made. This was swiftly followed by Newton's 1672 "New theory of light and colour," sometimes viewed as his first scientific paper. This had the effect of promoting his new reflecting telescope design by exaggerating the chromatic aberration from which refracting telescopes suffered. This exaggeration, which disturbed **Robert Hooke** and **John Flamsteed**, was reinforced in Newton's *Opticks* of 1704, and effectively blocked achromatic lens development until 1740.

Using a prism and a chink of sunlight, Newton claimed to demonstrate that white light was composed of various colored rays that had merely been separated by the prism. Hooke disagreed, commenting that he could not see the necessity for such an inference. Then, drawing from his alchemical studies, in a 1675 letter to the Royal Society, Newton formulated his immortal concept of the seven colors of the rainbow.

Newton was taught the new physics of **René Descartes**, and accepted the Cartesian vortex theory of planetary motions, adhering to it until the early 1680s, but he modified it with his own view of a downward-flowing gravity ether: This had a "sticky and unguent" nature as it pulled objects downward, as he explained in his 1675 letter. He was, at the time, immersed in the alchemical tradition, and this theory emerged from it. Modern Newtonian scholarship has shown that Newton's early computations in the plague years concerning the *conatus recedendi* (or tendency of the huge ethers rotating round the Sun to recede) cannot be seen as an early perception of the inverse-square law of gravitational attraction, contrary to several centuries of interpretation.

Around 1679/1680, in addition to his arduous alchemical labors on such matters as preparing the elixir and fixing antimony, Newton's major interest lay in decoding the Apocalypse (Revelation) in order to analyze a presumed theological heresy of the fourth century concerning the Holy Trinity. The Platonist philosopher Henry More at Trinity College recorded the enthusiasm with which Newton participated in discussion on such issues. We should therefore hesitate before accepting the received notion that Newton then linked **Johannes Kepler**'s first two laws of planetary motion to dynamical principles, as he later claimed and as many books have repeated. But no documents of this character exist (as science historian D. T. Whiteside demonstrated) dateable prior to the autumn of 1684, when, at **Edmond Halley**'s bidding, he struggled with the great problem, and solved it.

As a student, Newton had observed the comet of 1664 (C/1664 W1), but it was too distant for any orbital parameters to be inferred. The comets C/1680 W1 and 1P/1682 Q1 (Halley) were decisive for his thinking, with characteristics that seemed to be pointing to features of the to-be-born gravity theory. That of 1680 had its perihelion a mere fraction of the solar radius, yet was well outside the plane of the Solar System and so had little implication for the solar-vortex theory. Newton scrutinized it and received data from Flamsteed, after which he declined to believe what Flamsteed was telling him, that "ye two comets," one of which faded away in the evening sky and the other of which reappeared in the morning sky a week later, were one and the same. Years later, the comet merited 17 pages of his *Principia* for its parabolic orbit – but, in 1680, discussing its motion in the context of his vortex-theory with Flamsteed, he preferred **Giovanni Cassini**'s view that it was in orbit round Sirius. Hooke's seminal words to him, written on 6 January 1680, that throughout the Universe a force of gravity worked so that "the Attraction is always in a duplicate proportion to the distance from the Center Reciprocall …" had hitherto lain dormant in his mind. Then the only bright, periodic comet (later named after Halley) conveniently turned up in 1682, orbiting within the ecliptic plane but in the reverse direction to the planets, and this acted as a trigger.

Newton's alchemical laboratory fire then went out for a couple of years. In the summer of 1684, following a visit of Halley, a more austere, left–brain process began as he apprehended that the "two comets" of 1680 were in fact one. In November of 1684 Halley received a draft of *De Motu*, which employed the inverse-square law. Newton there demonstrated the link to Kepler's first and second laws, using a cumbersome logic based upon relative volumes. Dealing with small changes in an elliptical orbit, it was a rudimentary integration procedure. The proof thus laboriously constructed required the rest of *De Motu* as its context, because it used the concepts there developed of force, impulse, and momentum conservation.

In the spring of 1685, Newton accomplished his "moon-test" computation, justly his most famous. For his predecessors, the 27.3-day sidereal lunar orbit had carried an astral meaning, from the Moon's passage against the starry constellations, but Newton ignored that and viewed it only as resulting from a central force. He became able in the 1680s to compute acceleration by a centripetal force. "If stopped," he explained, the Moon would fall a distance in 1minute, equal to the distance an object on Earth would fall in 1 second; a 60-fold ratio was employed, related to the 60 Earth-radii lunar distance. There was no computation of acceleration, of "g," despite the many textbooks that have averred this. Newton was now able to treat uniform circular motion as accelerated, toward its center.

Then began the great synthesis of many physical ideas in the 2 1/2 years during which Newton wrote his *Principia*, from the autumn of 1684 to March of 1687. **Nicolaus Copernicus** had made the Sun stationary, which Newton transformed into the immobility of the Solar System's center of mass. Newton incorporated the work of **Galileo Galilei**, who had first discerned accelerated motion in free fall, where distance fallen in equal times goes as the sequence of odd numbers and is the same for all objects, replacing the old notion that heavy bodies fall faster. Descartes, and now Newton, affirmed that one physics should link the Earth and sky, demolishing the old duality between the "sublunary" world and the immutable heavens: Newton extended the work of **Jean Buridan**, who had developed the notion of impetus, whereby a body keeps moving, in place of **Aristotle**'s notion that a body moves so long as it is pushed. Robert Boyle had described a vacuum at the top of a mercury column, which Newton now envisaged throughout the immensity of space; Newton derived Kepler's three laws of planetary motion, which had ellipses replacing circular epicycles; Barrow, Newton's mathematics teacher at Trinity, had taught a rudimentary calculus concerning "just nascent quantities," which Newton employed to describe the motions of bodies; last but not least, from Hooke came Newton's inverse-square law of gravitational attraction. A new Universe gleamed, rational to the core.

In dealing with the three-body problem, Newton's calculations were given to five decimal places and eight-figure accuracy, generating a huge error (200%) for lunar mass. He found the Earth–Moon mass ratio to be 22:1 rather than the currently accepted 81:1. Newton thus left to posterity an ultra-dense Moon. As a result, his first computation of the Earth–Moon barycenter in 1713 (for the *Principia's* second edition) located it outside the Earth, from which derived the main error in his historic computation, linking the fall of an apple to the lunar orbit.

Newton also explained why the Earth has two tides a day, a question that had so baffled Salviati and Sagredo in Galileo's *Dialogue*, and indeed many previous natural philosophers. Newton formulated the inverse-cube law of tidal pull, whereby "the force of the moon to move the sea varies inversely as the cube of its distance from the earth." This accounted for the Moon having a larger tidal pull than the Sun, although having only a tiny fraction of its gravity. Thereby he could explain why there are two high tides a day aligned with the Moon. Newton intuited this law with little by way of explanation, so his contemporaries such as Halley and **David Gregory** attempting to explain this tidal argument could do so only in a qualitative sense.

The mighty synthesis thus accomplished had no practical use to astronomers. British ephemerides (for planetary and lunar positions) were not improved: Paris became the main center of their production over this period. After his 1693 nervous breakdown, Newton made one further scientific endeavor. He grappled with lunar theory in 1694/1695, using Flamsteed's new, high-precision data. This was the supreme scientific problem of the age, holding out the promise of finding longitude at sea. Could Newton explain the Moon's erratic path using his gravity theory, since the rest of the Universe obeyed it? He could not (in Whiteside's view). His hitherto respectful partnership with Flamsteed suffered from this, with a (successful) ploy of laying the blame for the failure upon the astronomer, as if he had demurred in sending the data. A fruit of this struggle appeared in 1702, with a lunar "theory" which was, paradoxically, not evidently based upon gravitational principles. This 1702 *opus* was the most frequently reprinted work of Newton's in the first half of the 18th century: In seven steps of "equation" it obtained a final lunar longitude, accurate to several arc minutes.

A modified version appeared in Book III of the *Principia's* 2nd edition of 1713. Thus began the idea of ancillary equations, as a means of solving the three-body problem. Newton reintroduced epicycles into astronomy, a century after Kepler had banished them: His neo-Horroxian 1702 lunar theory was laden with four of them, and as such they reappeared in his *Principia*. French sources could never believe that this model with its wheels moving upon wheels had been deduced from the gravity theory, while English histories soon managed to retell the story using the mid-18th-century theories of **Leonhard Euler** or **Johann Tobias Mayer** as being "Newtonian."

In his *Algebra* of 1685, **John Wallis** commented upon a mathematical tract of the 1660s by Newton, *De analysi*, which Newton would not allow to be published; while admiring certain conventions and nomenclature, Wallis perceived in it no germ of a new fluxions theory, nor did anyone else in the 17th century, despite wide circulation of the manuscript. Only retrospectively, during the great fluxions battle with **Gottfried Leibniz** at the beginning of the 18th century, were such claims first advanced. (The *Principia* contained integral but not differential calculus, the former having developed somewhat earlier than the latter.) Newton's *Arithmetica Universalis* published in 1707 and taken from his mathematical lecture notes of the 1680s, compiled by **William Whiston**, enjoyed a much greater popularity in its time than either the *Principia* or *Opticks*, but it contained no trace of fluxions, Newton's term for the differential calculus, and rather argued against the concept of introducing arithmetical terms into geometry.

Albert Einstein once declared that, "the solution of the differential law is one of Newton's greatest achievements," but the equations $F = ma$ and $F = m\,\mathrm{d}v/\mathrm{d}t$ were invented around 1750 by Euler in Berlin; no one in Newton's lifetime had heard about them. The Berlin Academy of Sciences showed no inclination to view Euler's great discoveries as having been anticipated. What the *Principia* stated was, merely, "change of motion is proportional to motive force impressed" with quantity of motion having been earlier defined as the product of mass and velocity. That was a statement about impulse as proportional to change in momentum and uses no rate-of-change concept. As I. Bernard Cohen has observed, Newton never wrote anything resembling F = kmv. The *Principia* with its geometrically structured proofs, achieved a depth of inscrutability unmatched by any other scientific text. Much of what is called "Newtonian" science is the reformulation of Newton's work using Leibnizian calculus, a task accomplished largely on the Continent in the 18th century.

The myths that surround the image of Newton tend to exaggerate the extent to which he used "fluxions," but not always. For example, it is often asserted that he developed the equation $F = GMm/r^2$, a formula which was not, in fact, published in his lifetime. In "a famous but delusive phrase" (Rupert Hall), Newton averred in 1712 that his masterwork had first been composed in fluxional terms and then, later on, recast into a geometrical format. Generations of historians have reaffirmed that Newton had first composed his *Principia* in fluxional form and then recast it into its inscrutable geometric format, but not until 1975 did. D. Whiteside disprove this notion and lay it to rest.

"Newton's method of approximation" was invented in 1845 by John Simpson, known today for his "Simpson's method" for finding the approximate area under a curve. It is an iterative technique where the same equation is reused, and employs the Leibnizian calculus. Newton's own method of approximation, described in his *De Analysi* and which he used to solve the Kepler equation for elliptical motion, was neither iterative nor fluxional. For each step of approximation it generated a new and different equation. Simpson was not eminent enough to hang onto the credit for his invention, which became attributed to Newton in the latter half of the 18th century.

Few paid Newton more golden compliments than did Leibniz: "taking mathematics from the beginning of the world to the time of Sir Isaac, what he had done was much the better half," he wrote to the Queen of Prussia in 1701. But after his mistreatment by the Royal Society in the fluxions dispute, he described Newton as "a mind neither fair nor honest." Leibniz first published papers on the differential calculus in 1684; these were seminal for the European development of the subject. Newton's first work on the subject appeared in 1704, *De Quadratura*, which gave what we would call implicit functions. It did not describe time-dependent functions or how to find the gradient of a curve, and was primarily about methods of integration.

Newton wrote over a million words on chemistry alchemy, and believed that transmutation could possibly make or unmake gold, as expressed in his one published chemical alchemical text, *De Natura Acidorum* (1710), which described that process. He read alchemical texts eagerly, but seems not to have written like an alchemist; he sought no path of redemption or perfection through such labors. Ultimately his relation to the western alchemical tradition was that of terminator. Once his *Opticks* had affirmed the atomic view ("God in the Beginning form'd Matter in solid, massy, hard, impenetrable moveable Particles … even so very hard, as never to wear or break in pieces"), the colorful language of alchemy had to transform into particulate affinity theory during the 18th century.

Hardly was the ink dry from his *Principia* in March 1687 when Newton was elected to represent Cambridge University in parliament in an attempt to defy the king's promotion of Roman Catholic professors. This morally courageous act put his career at risk and got him sternly rebuked from the feared judge Jeffreys. Two years later the king had fled the country, Jeffreys was in the Tower, and Newton was in parliament. When in 1695 he became warden of the Mint, the nation's recoinage was successful, and the Bank of England first floated paper money, a difficult exercise in credibility. When Newton was elected president of the Royal Society in 1704, its membership and prestige climbed steadily. From being the most reclusive of scholars, where most of the tales about him concern his absent-mindedness, he became a man of public affairs: Member of parliament, Justice of the Peace, knight, president of the Royal Society, and master of the Mint. In his religious views, Newton was probably a mortalist (disbelieving in human survival after death) and an anti-Trinitarian, either of which would have utterly debarred him from holding public office.

In the last year of his life, in a Kensington garden far from the bustle and fumes of London and while having tea with **William Stukeley**, Newton first told his story of the apple. Thus had the law of gravity dawned upon him. He located it in 1666, as London burnt and the plague raged. Earlier narrations beginning in the 1690s had involved his Mother's garden at Grantham but lacked mention of this fruit. The neo-Biblical simplicity of this story proved irresistible, and it has flourished ever since.

Nicholas Kollerstrom

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Nicetus

➜ **Hicetus**

Nicholas Cusanus

➜ **Krebs, Nicholas**

Nicholas of Lynn [Lynne]

Flourished **1386**

Nicholas was a Carmelite friar in Oxford. His almanac (then called *Kalendarium*) acknowledged – and provided a remedial table to correct for – the error in the Julian calendar, which by Nicholas's time had led to a 12 March equinox date. The *Kalendarium* of Nicholas was used by **Geoffrey Chaucer** in his *Canterbury Tales*.

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Nicholas of Cusa

➜ **Krebs, Nicholas**

Nicholson, Seth Barnes

Born **Springfield, Illinois, USA, 12 November 1891**
Died **Los Angeles County, California, USA, 2 July 1963**

American observational astronomer Seth Nicholson is probably best known for the discoveries of four satellites of Jupiter, numbers 9–12, but his most significant contribution may have been the discovery, with **Charles St. John** that the atmosphere of Venus contains at most a vanishingly small amount of water and molecular oxygen. Nicholson was the son of a schoolteacher and principal with a master's degree in geology from Cornell University. He received a BS from Drake University in 1912 (and an honorary LLD in 1949). He and Drake University classmate Alma Stotts went on to the University of California (Berkeley) and Lick Observatory for graduate work in astronomy and married in 1913, having three children. Nicholson was very prompt in completing the traditional Lick Observatory requirement to determine the orbit of a comet accurately enough for publication with a paper on the orbit of comet C/1912 V1 coauthored by O. Lanzendorf that same year. He supported his graduate studies by serving as an instructor of astronomy, completed the Ph.D. in 1915, and accepted an appointment at Mount Wilson Observatory, where he remained formally until his retirement in 1957 and informally for the rest of his life. Nicholson served as a civilian with the Office of Scientific Research and Development in 1944 and later with the Atomic Energy Commission.

Nicholson discovered his first jovian satellite (Sinope) while still a graduate student and a volunteer assistant at Lick when most of the astronomers were on an eclipse expedition to Russia. Therefore he had extra time for observing with the 36-in. Crossley. He had been assigned the task of photographing the known, faint outer satellites in order to improve their orbits; and, on the plates taken to track the eighth moon (discovered in 1908 by **Philbert Melotte**) found Jupiter IX. In 1938, while other Mount Wilson astronomers were at the general assembly of the International Astronomical Union in Stockholm, Nicholson once again had extra telescope time, this time at the 100-in. Hooker, to survey the region around Jupiter. He set the telescope to track Jupiter, which left faint stars as elongated trails on the plates and satellites carried along by Jupiter as small circular images. This technique revealed Jupiter X and XI. Jupiter XII came in 1951.

Systematic observation of Neptune showed Nicholson that it should be possible to determine the mass of its satellite Triton from the motion of Neptune around their mutual center of mass. This was done by **Harold Alden** in 1942.

Nicholson spent many years on the solar program initiated by **George Hale**. He collected data on sunspot numbers and magnetic fields over several sunspot cycles and looked for correlations with terrestrial phenomena using a spectroheliograph sensitive to polarization. In 1922, he and St. John looked hard for features due to water vapor and molecular oxygen in the spectrum of Venus. They concluded that the amount of oxygen must be less than 0.1% of what would be found above the same ground area on Earth and that there was less water vapor than would make a 1-mm layer if it precipitated out as liquid.

The most important long-term contribution was Nicholson's development with **Edison Pettit** in the 1920s of a vacuum thermocouple as a detector for infrared radiation beyond the longest wavelengths to which photographic emissions are sensitive. This enabled them to measure the thermal infrared emission from, and therefore the surface temperatures of the Moon, and terrestrial planets, and temperatures of the visible layers in the atmospheres on the Jovian planets. They found, for instance, that the subsolar point on Mars was sometimes above freezing and that the difference between day and night temperatures on Venus was relatively small, indicating that, although its rotation is slow, it does not always keep the same face toward the Sun.

Nicholson was somewhat unfairly drawn into the controversy about the rotation and distance of the spiral nebulae. He remeasured some of the plates on which **Adriaan van Maanen** thought he had seen motion outward along the arms (corresponding to rotation with leading arms) and tentatively confirmed the motions, but later, under the guidance of **Edwin Hubble**, he measured some of the plates again and came to agree with Hubble that there was no detectable proper motion.

Nicholson was elected to the National Academy of Science in 1937 and received the Bruce Medal of the Astronomical Society of the Pacific [ASP] at their June 1963 meeting in San Diego. He was by then too ill to attend and participated in the ceremony *via* a telephone hookup. Nicholson had twice served as president of the ASP and edited its *Publications* for some years, remaining on its board of directors, publications committee, and lecture committee until his death. He was a scoutmaster from 1923 to 1938, served on a boy scout troop committee and as a commissioner, and received scouting's Silver Beaver Award.

Norriss S. Hetherington

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Niesten, Jean Louis Nicholas

Born **Vise near Liège, Belgium, 4 July 1844**
Died **probably Brussels, Belgium, 27 December 1920**

Louis Niesten joined the staff of the Royal Observatory (Brussels) in 1878, and in that year discovered the Great Red Spot on Jupiter – independently of, and 2 months after, **Carr Pritchett**. He was an assiduous observer of the planets, especially Venus, Jupiter, and Mars.

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Nietzsche, Friedrich Wilhelm

Born **Röcken bei Lützen, Sachsen, (Germany), 15 October 1844**
Died **Weimar, Germany, 25 August 1900**

German philosopher Friedrich Nietzsche was influential during an era when scientists were working out the ramifications of the laws of thermodynamics. In this light, his vision of "eternal recurrence" in infinite time may be viewed as a cosmological theory or as a concept in thermodynamics, related to the more quantiative Poincaré recurrence time.

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Nightingale, Peter

Flourished **Denmark, 1290–1300**

The life of calendricist Peter Nightingale is only fragmentarily known. It is here assumed that Petrus de Sancto Audomaro (Peter from Saint Omer) is also identical to Peter Nightingale.

Possibly he is identical to the unknown astronomer at Roskilde, Denmark, who in 1274 measured day by day the declination of the Sun and computed the corresponding lengths of the day, data later used by Nightingale and **William of Saint Cloud** in their calendars.

Nightingale must have left Denmark in the 1280s to study at Bologna. There, he obtained a master's degree, and lectured on astronomy, or rather astrology, at the Faculty of Medicine. His popular Tabula Lunae, a diagram to determine the zodiacal sign of the Moon for every month, most likely is from this period. He also made a similar diagram to find the reigning planet for every day.

Around 1292, Nightingale left Bologna for Paris, at this time a flourishing center of astronomy comprising names like **Campanus of Novara**, **John of Sicily**, and William of Saint Cloud. In Paris, Nightingale worked out a new edition of **Robert Grosseteste**'s calendar, which had expired in 1283 at the end of its 76-year period based on four Metonic cycles of 19 years. Nightingale made the correction needed for another 76 years starting in 1292, improved the Moon tables, and added information about the Sun's declination and length of the day. This calendar and its subsequent prolongation became a standard in much of Europe in the 14th century.

Another achievement of Nightingale in practical astronomy was his improved equatorium, found in the "Tractatus de Semissis" from 1293. An equatorium is an analog computing device, based on the Ptolemaic model of the planetary system, designed to find the longitudes of the planets. Earlier equatoria had the drawback of requiring a separate unit for each planet. In Nightingale's equatorium they were merged into a single unit, thereby reducing considerably the number of graduated circles to be drawn. He seems to have worked together with William of Saint Cloud on this project.

Apart from the highlights described earlier, mathematical tables and commentaries to astronomical works of others are found among the extant manuscripts of Nightingale. Of the commentaries, the one on the combined quadrant and astrolabe by **Jacob ben Mahir** is of particular importance because it explained and spread knowledge of this ingenious instrument.

After his years in Paris, the only known information about Nightingale's life is that in 1303 he held a position as canon at the Roskilde Cathedral.

Truls Lynne Hansen

Alternate names

Petrus (Philomena) de Dacia
Petrus Dacus [Danus]

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Nikolaus von Cusa

Krebs, Nicholas

Nīlakaṇṭha Somayāji

Born **Tṛkkaṇṭiyūr, (Kerala, India), 14 June 1444**
Died **after 1501**

Nīlakaṇṭha Somayāji was one of the foremost names of the Kerala School, which produced several outstanding astronomers and mathematicians over the centuries. The end of the Kerala School (about 1600) seems to have coincided with the fall of the Hindu Vijayanagar empire. Nīlakaṇṭha was the son of Jātaveda and a performer of the Soma sacrifice. His student days were spent in the house of another Kerala astronomer, **Parameśvara**, although his own teacher was Parameśvara's son, Dāmodara.

Nīlakaṇṭha's most important text is the *Tantrasaṅgraha*, a comprehensive treatise on astronomy written in 1501. The *Tantrasaṅgraha* reveals Nīlakaṇṭha to be a follower of the *dṛggaṇita* system of astronomy founded by Parameśvara. He prepared several other important texts, including an extensive commentary on the *Āryabhaṭīya* of **Āryabhaṭa I**. He also wrote the *Golāsara*, which explains the parameters of his planetary models, the celestial sphere, and other computational principles.

Nīlakaṇṭha combined the earlier and incomplete heliocentric models of Āryabhaṭa I and Parameśvara within his *Tantrasaṅgraha* and developed a fully heliocentric system, wherein the five planets moved in eccentric orbits around the Sun. He also made significant contributions to geometrical theorems and infinite series.

A. Vagiṣwari

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Nininger, Harvey Harlow

Born **Conway Springs, Kansas, USA, 17 January 1887**
Died **Westminster, Colorado, USA, 1 March 1986**

Harvey Nininger has been called the father of modern meteoritics. As an exceptionally successful meteorite hunter, Nininger collected specimens of 226 meteorite falls not previously identified, of which only eight were actually seen to fall. He began collecting and studying meteorites in 1923, during a period when the leading scientists of the day thought there was nothing left to learn from them. By the time Nininger retired, the Space Age had dawned and meteorites had become a key component of research into the origin of the Earth and the Solar System.

Nininger was the son of farmers James Buchanan and Mary Ann (*née* Bower) Nininger. In their simple home there were only two books, the Bible and a mail order catalog. Science was considered the work of the devil. As a result, Nininger was 20 years old before he passed an eighth-grade equivalency test and entered Northwestern State Normal College at Alva, Oklahoma, eventually matriculating from McPherson College in Kansas. After receiving a B.S. in Natural History from McPherson College in 1914 and an A.M. from Pomona College in California in 1916, Nininger worked as a biologist, serving both as a professor of biology at several small colleges and as a field entomologist for the United States Department of Agriculture.

In 1923, while teaching at McPherson College, Nininger learned of the existence of meteorites through an article in *Scientific Monthly*. Three months later, a brilliant fireball passed over the town as he was walking home. Nininger set out to find the meteorite that produced the fireball. Although he did not find that meteorite, he did find another one, and his life changed forever. Meteorites became his passion: Nininger set out to learn everything he could about them. He also started a program to collect meteorites, although he was not able to generate much support for this endeavor. In 1928, George Merrill, head curator of the Smithsonian Institution, had told him, "Young man, if we gave you all the money your program required and you spent the rest of your life doing what you propose, you might find one meteorite." However, Nininger was not dissuaded and devised a successful program of collecting meteorites based on educating the people who work the land and offering to buy the meteorites that they found. In 1930, Nininger resigned his professorship at McPherson College and moved to Denver, Colorado, where he joined the staff of the Colorado Museum of Natural History (now the Denver Museum of Nature and Science). He spent the next 16 years searching for and collecting meteorites and investigating meteorite craters. In 1932, Nininger and Frederick Leonard (1896–1960), professor of astronomy at the University of California at Los Angeles, founded the Society for Research on Meteorites (later renamed the Meteoritical Society).

In 1946, Nininger left Colorado with his collection of eight tons of meteorites to establish the American Meteorite Museum, near Winslow, Arizona. His intent was to use the tourist income from the museum admission and sale of meteorite specimens to support his studies of the nearby Barringer Meteor Crater. In 1939, he had been granted a formal permit to continue his investigation of the crater. Although Nininger had originally accepted the idea that the meteorite lay in the bottom of the crater, he eventually was convinced by the calculations of **Forest Moulton** that the meteorite had exploded on impact. His discovery in 1948 of metallic spheroids in the area around the crater provided proof of the explosion theory. These spheroids were produced by condensation of the vaporized meteorite from the fireball that resulted from the impact. Thousands of tons of them, representing the majority of the mass of the impactor, are present in the soil surrounding the crater.

Rapid expansion of interest in meteorites inevitably led to differences of opinion and controversy. Nininger was a participant in several of these early disputes. In 1941, Lincoln LaPaz published a theory of meteorites composed of antimatter, a topic of high interest as popular knowledge of the emerging disciplines of atomic and nuclear physics began to reach the broader scientific community. LaPaz speculated that craters otherwise devoid of evidence of a meteoric origin might have been formed by antimatter or "contraterrene" meteorites that exploded as they annihilated normal terrestrial matter. Nininger properly invoked Occam's razor in pointing out that much more plausible explanations could be put forward to justify the existence of such craters. The dispute escalated in a series of rebuttals on both sides of the argument before gradually dying out during World War II as the society ceased all professional publishing activities. The debate over the contraterrene meteorites was only the first of several acrimonious disputes between Nininger and LaPaz. Their feud came to a head at the 1949 meeting of the Meteoritical Society, when Nininger and his wife Addie resigned from the society after a priority dispute erupted at the meeting. By that time, the society was polarized by the contentious debates which appear to have involved, in addition to technical issues, LaPaz's view that Nininger's effort to earn a living by selling meteorites was unprofessional and not in the best interest of science. Their fights nearly destroyed the society in the view of a number of members who witnessed the years of wrangling.

In late 1948, Nininger's permit to collect meteorites on Barringer Crater Company property was withdrawn, limiting his research on the crater to government land. Shortly thereafter, highway traffic was rerouted so that it no longer passed in front of the museum. In 1953, the American Meteorite Museum was moved to Sedona, Arizona, where it operated until Nininger retired in 1960.

The meteorites that Nininger collected are a permanent legacy to his work. About 20% of his collection was purchased by the British Museum of Natural History in 1958. The remainder of his collection was acquired by the Arizona State University [ASU] in 1960. The Nininger Meteorite Collection became the centerpiece of ASU's Center for Meteorite Studies, which currently houses the largest university-based meteorite collection in the world.

Nininger received an honorary Sc.D. degree from McPherson College in 1967 and an honorary Sc.D. from Pomona College in 1976. The Meteoritical Society honored him with its highest award, the Frederick C. Leonard Medal, in 1967. During his lifetime he wrote four books, three booklets, and more than 150 scientific papers.

On 5 June 1914, Nininger married Addie Delp, and their union resulted in three children, Robert, Doris, and Margaret. Addie was an integral part of Nininger's meteorite program, running the household (both at home and during extended field trips), acting as field assistant, helping to run the Meteorite Museum, serving as chair of the Committee on Catalog of the Society for Research on Meteorites, and coauthoring "The Nininger Collection of Meteorites." Although Addie died in 1978, Nininger continued to live a full life, attending the Meteoritical Society's 50th anniversary meeting in Mainz, Germany in 1983. Nininger's field program was carried on by his son-in-law Glenn I. Huss (husband of Margaret), who operated the American Meteorite Laboratory in Denver until his death in 1991 and who collected an additional 239 meteorites previously unknown to science.

Gary Huss and *Peggy Huss Schaller*

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Nīsābūrī: al-Ḥasan ibn Muḥammad ibn al-Ḥusayn Niẓām al-Dīn al-Aʿraj al-Nīsābūrī

Born **Nīshāpūr, (Iran)**
Died **(Iran), 1329/1330**

Niẓām al-Dīn al-Aʿraj al-Nīsābūrī composed several widely studied astronomy texts in the 14th century, which indicate the integration of astronomy within a tradition of religious scholarship in Islamic civilization. He was born into a Shīʿa family with roots in Qum.

The sources say little about Nīsābūrī's early life and education. By mid-1303, Nīsābūrī had begun to write *Sharḥ Taḥrīr al-Majisṭī* (Commentary on the recension of the *Almagest*), a commentary on **Naṣīr al-Dīn al-Ṭūsī**'s *Taḥrīr al-Majisṭī* (Recension of the *Almagest*) of **Ptolemy**. As was true for many commentaries in Islamic science, Nīsābūrī did not simply explain the meanings of the original text but included the results of his own work as well. In the *Sharḥ*, Nīsābūrī devoted much space to observations of the obliquity of the ecliptic and to **ʿUrḍī**'s work on instrument construction. Nīsābūrī also investigated whether Venus and Mercury had been observed to transit the Sun, an observation that would determine the position of the Sun with respect to Mercury and Venus. In 1304, Nīsābūrī arrived in Azerbaijan; by 1306 he was in Tabrīz, the largest city in Azerbaijan, where he completed the *Sharḥ*. In Tabrīz, Nīsābūrī also began to study with the astronomer **Quṭb al-Dīn al-Shīrāzī**.

Nīsābūrī completed his second major text, *Kashf-i ḥaqā'iq-i Zīj-i Īlkhānī* (Uncovering of the truths of the Īlkhānid astronomical handbook), in 1308/1309. The *Kashf*, a commentary on Ṭūsī's astronomical handbook entitled *Zīj-i Īlkhānī*, refers to the *Sharḥ*. Nīsābūrī wrote the *Kashf* right after the *Sharḥ* inasmuch as the *Kashf* focused on topics that were closely connected to the *Sharḥ*, such as the observation and prediction of planetary positions.

The *Tawḍīḥ al-Tadhkira* (Elucidation of the *Tadhkira*), a commentary on Ṭūsī's *al-Tadhkira fī ʿilm al-hayʾa* (Memento on astronomy), was Nīsābūrī's third and final text on astronomy. A cross-reference to a *Tadhkira* commentary in the *Sharḥ* shows that Nīsābūrī had begun to compose the *Tawḍīḥ* before he finished the *Sharḥ*.

In the *Tawḍīḥ*, Nīsābūrī investigated theoretical topics, such as non-Ptolemaic models for planetary motions, and topics that combined theory and observations, such as physical hypotheses that accounted for the observed variations in the obliquity of the ecliptic. Although the *Sharḥ* and the *Tawḍīḥ* evinced a mastery of the technical innovations of Islamic astronomy, Nīsābūrī did not make significant advances with the most difficult questions. Shīrāzī, however, did, and the weight of Shīrāzī's reputation may explain the coincidence of the date of the appearance of the *Tawḍīḥ* with the date of Shīrāzī's death in 1311.

Īlkhānid ministers patronized Nīsābūrī's scientific work. The Īlkhānids were the descendents of Hülegü Khān (died: 1265), who had patronized the construction of the famous observatory at Marāgha, Azerbaijan, where both Ṭūsī and Shīrāzī worked. Nīsābūrī dedicated the *Sharḥ* to Khwāja Saʿd al-Dīn Muḥammad ibn ʿAlī al-Sāwajī. Sāwajī was chief minister (along with Rashīd al-Dīn) under Īlkhānid Sultan Ghāzān (reigned: 1295–1304) and continued in that post until 1312 when Rashīd al-Dīn had him executed. Shīrāzī's acquaintance with Sāwajī would have provided a way for Nīsābūrī to gain Sāwajī's patronage. There is a 1309 copy of the *Kashf* dedicated to al-Sāwajī. Nīsābūrī dedicated the *Tawḍīḥ* to a certain ʿAli ibn Maḥmūd al-Yazdī.

Because the *Sharḥ* and the *Tawḍīḥ* were clearly written and intended for nonexpert astronomers, they became important components of a tradition of religious scholarship that included astronomy. Many manuscripts of the *Sharḥ* and *Tawḍīḥ* have ownership statements from the libraries of *madrasa*s (colleges of religious studies). Two reports attest to how the *Tawḍīḥ* was the most important text at **Ulugh Beg**'s *madrasa* in Samarqand for the study of the *Tadhkira*. Later works on Islamic astronomy, also with *madrasa* library ownership statements, refer to Nīsābūrī as *al-shāriḥ* (the commentator).

Nīsābūrī's best-known text, his Quran commentary entitled *Gharāʾib al-Qurʾān wa-raghāʾib al-furqān* (The curiosities of the Quran and the *desiderata* of the demonstration), demonstrates the importance of science for religious scholars. Nīsābūrī in general relied heavily on Fakhr al-Dīn al-Rāzī's (died: 1209) al-*Tafsīr al-kabīr* (The great commentary), but frequently disagreed with Rāzī about the use of science and philosophy *(falsafa)* to portray nature. The *Gharāʾib* reflected Nīsābūrī's scientific education and privileged the views of the natural philosophers *(falāsifa)*, while Rāzī had favored the positions of the theologians *(mutakallimūn)*. Through subtle rewordings and emendations of scientific detail, Nīsābūrī rebutted Rāzī's critique of science and *falsafa* in his portrayal of nature. Nīsābūrī completed *Gharāʾib* in 1329/1330, a date which the bio-bibliographers consider to be the date of his death.

Robert Morrison

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Nishikawa, Joken

Born **Hizen, (Nagasaki and Saga Prefectures), Japan, 1648**
Died **Nagasaki, Japan, 1724**

Joken Nishikawa strove to identify the practical and theoretical merits and defects of both Chinese and European astronomy. He was the son of a provincial official from Nagasaki. Joken was his penname, but he also used Tadahide, among others, as a first name throughout his life. Nishikawa learned astronomy from Kentei Kobayashi and developed Confucian scholarship under the tutelage of Soju Nanbu. At the age of 50, he retired and devoted himself to astronomy and calendar studies. As his writings on astronomy, geography, and pragmatic matters received recognition, Nishikawa was invited to Edo (present–day Tokyo) by the eighth *Shogun* Yoshimune Tokugawa in 1719 to discuss his ideas about Eastern and Western knowledge.

Nishikawa's productivity was evident in a number of fields spanning the intellectual and purely philosophical as well as the pragmatic and empirical. He passed on a sense of scholarship to his children and others. Nishikawa's third son, Masayoshi (1693–1756), learned astronomy from his father and was assigned to the Tenmongata (Bureau of Astronomy) as an official astronomer in 1740.

It is easy to oversimplify the changes that occurred in scientific thinking in 17th-century Edo Japan. This period started with a strong reliance on Chinese classics and the theory of five elements as exemplified in **Gensho Mukai**'s commentaries on western astronomical concepts. As the century closed, these traditions were giving way to an amalgamation of study that might be termed "pure" astronomy in the modern sense.

Nishikawa was somewhat of a pioneer in this intellectual movement; his greatest contribution was to delineate matters of speculative philosophy relative to matters best studied by empirical means. In his 1712 work, *Tenmon Giron* (Discussions of the principles of astronomy), Nishikawa discussed the moral and physical dualism of "two heavens." One was the heaven of *Meiri,* which Nishikawa considered a realm of philosophical speculation and most similar to the more classic idea of Li. The second was that of *Keiki*, which he considered the realm of empirical investigation and most like that of the classic Qi.

While some have considered Nishikawa to be closed to western concepts and rigid in his Confucian upbringing, his work must be viewed within its context. His intellectual work helped to free his own empirical investigations as well as those of many who followed. In *Ryougi Shusetsu* (An explanation of collected materials on celestial and terrestrial globes, 1714), he concerned himself with geographical as well as astronomical phenomena from the standpoint of both empiricism and pragmatism. While not rejecting Chinese Classics, he felt that western-based methods in areas such as navigation were clearly superior to those that had been coupled with the more mystic sides of classical Chinese works. He maintained skepticism toward the traditions of ancient Chinese classics as well as European ideas that he felt did not conform to empirical verification. Nishikawa abandoned traditional portent astrology but just as strongly rejected the zodiacal astrology of the west. To those who followed, he advocated relying on empirical verification of postulates rather than blind acceptance of any dogma, whether from China or Europe.

Steven L. Renshaw and *Saori Ihara*

Alternate name

Tadahide

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Nakayama, Shigeru (1969). *A History of Japanese Astronomy: Chinese Background and Western Impact*. Cambridge, Massachusetts: Harvard University Press. (Nakayama presents an extensive section on Nishikawa's commentary, and with detailed explanations of both western and eastern precepts, gives a clear picture of the epistemological base from which most work in early Edo Japan was developed.)

——— (1978). "Japanese Scientific Thought." In *Dictionary of Scientific Biography*, edited by Charles Coulston Gillispie. Vol. 15 (Suppl. 1), pp. 728–758. New York, Charles Scribner's Sons. (In this extensive article, Nakayama clarifies differences between epistemological views in Europe and Japan at the time Nishikawa lived. Whereas his explanation of Chinese classics require the reader to find supplemental material in order to grasp their full impact, this article provides a necessary base to understand the development of empiricism in the early Edo era as a mode of inquiry based on aspects of Aristotelian cosmology and pragmatic social need.)

Sugimoto, Masayoshi and David L. Swain (1989). *Science and Culture in Traditional Japan*. Rutland, Vermont: Charles E. Tuttle and Co. (This volume presents a comprehensive and scholarly view of scientific development in Edo Japan. Unlike many of his predecessors in Nagasaki, Nishikawa lived and worked in a time when the study of western concepts was somewhat freed from its previous relation to Christianity and the possible negative consequences of such a link. Sugimoto and Swain provide an excellent social backdrop for placing Nishikawa's work within a historical context.)

Nordmann, Charles

Born **Saint-Imier, now Bern Canton, Switzerland, 18 May 1881**
Died **Paris, France, 28 August 1940**

Charles Nordmann was an early pioneer of radio astronomy, the creator of multicolor photometry techniques, and a noted popularizer of astronomy. After receiving his *Licencié ès sciences* in 1899, he spent the following year at the Meudon Observatory, near Paris, under the directorship of **Pierre Janssen**. There, Nordmann began a study of the Sun, its activity, and effects on the Earth's magnetic field. From 1902 to 1903, he worked in the magnetic service at the Nice Observatory.

For his doctoral research at the University of Paris, Nordmann attempted to test the prediction of **Henri Deslandres** that the Sun ought to emit Hertzian (*i. e.*, radio) waves. He constructed a horizontal antenna, 175 m long, and installed it on the glacier of the Bossons (on Mont Blanc). Despite Nordmann's best efforts, no definite signals were ever received. Radio waves were not to be detected from the Sun until 1942. Nonetheless, Nordmann was awarded his degree (1903) under the guidance of **Jules Poincaré**.

That same year, Nordmann became an *auxiliaire* at the Paris Observatory and in 1905, was given the position of *aide-astronome*. **Maurice Löwy**, the director, encouraged him to pursue astronomical photometry. In 1906, as *astronome adjoint*, Nordmann devised a three-filter visual photometer that employed colored solutions to isolate the red, green, and blue regions of the spectrum. These experiments were performed on the observatory's 23-cm coudé telescope. His preliminary research investigated the apparent time differential (as a function of wavelength) on the observed minimas of eclipsing binary stars, a phenomenon independently described by **Gavril Tikhov**. Nordmann's observations were designed to test the potential dispersive powers of the interstellar medium on the speed of light, an idea ultimately rejected. However, recognition that the color index of a star (obtained by multicolor photometry) provided an effective measure of its surface temperature (given by the Planck curve) was first accorded to other observers.

During World War I, Nordmann worked in the field of sound-ranging techniques to locate the positions of German artillery. For these efforts, he was awarded the *Croix de guerre* in 1915 and made an *Officier de la Légion d'honneur* in 1918 (a *Chevalier* after 1912).

In 1920, Nordmann was appointed *astronome titulaire* at the Paris Observatory and began teaching at the École Supérieure des Postes et Télégraphes. He continued research in multicolor photometry and was succeeded in that effort by **Daniel Chalonge**. A significant part of Nordmann's work, however, was devoted to writing popular accounts of scientific discoveries, *e. g.*, *Einstein and the Universe: A Popular Exposition of the Famous Theory* (Paris, 1921).

Jacques Lévy
Translated by: *Suzanne Débarbat*

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Norton, William Augustus

Born **East Bloomfield, New York, USA, 25 October 1810**
Died **New Haven, Connecticut, USA, 21 September 1883**

William Norton wrote what was likely the earliest astronomical textbook produced in the United States; he was also a significant contributor to 19th-century ideas on the structure and behavior of cometary tails, terrestrial magnetism, and solar activity. By 1870, Norton went so far as to suggest, though without describing an exact mechanism, a link not only between solar coronal activity and Earth's auroral displays, but also with the observed activity in cometary tails.

Born the son of Herman and Julia (*née* Strong) Norton, William graduated in 1831 from the United States Military Academy at West Point, at that time arguably the premier technical, scientific, and engineering school in America. From 1831 to 1833, Norton served as both an artillery officer in the field during the Black Hawk War, and as an assistant professor of Natural and Experimental Philosophy at West Point. Norton left the army to become professor of natural philosophy and astronomy at the University of the City of New York (later renamed New York University) from 1833 to 1839. He then took a post as chairman (1839–1850) of mathematics and philosophy at the then struggling Delaware College (later renamed the University of Delaware), becoming interim president for a year (1850). A brief stint followed at Brown University, Providence, Rhode Island, as professor of natural philosophy and civil engineering. Norton finally settled down as professor of civil engineering at Yale's Sheffield Scientific School from 1852 until his death. He married Elizabeth Emery Stevens in 1839.

Seemingly inspired by the Great March Comet of 1843 (C/1843 D1), Norton acquired an early and lasting fascination with the behavior of comets, terrestrial magnetism, and the Sun. In 1844, Norton published an article, "On the Mode of Formation of the Tails of Comets," in the *American Journal of Science and Arts*. There, he explained the formation of cometary tails as originating from the evaporation of matter in the nucleus that was then swept away by the "repulsive force" of the Sun, which he suggested was magnetic rather than electrical in nature. Norton further explained the complexity of structures observed in cometary tails through a combination of the Sun's "repulsive force" *and* the centrifugal forces arising from a postulated rotating cometary nucleus. In 1859 and 1861, Norton presented evidence supporting his ideas from the widespread observations made upon Donati's comet (C/1858 L1). His studies of comets, terrestrial magnetism, and the Sun reached their fullest development in an 1870 paper, "The Corona Seen in Total Eclipses of the Sun." Here, Norton attempted to link phenomena of the corona and terrestrial magnetism by suggesting that the solar atmosphere itself was in fact an intense auroral display.

Norton was a natural and very successful teacher of astronomy; his textbooks reflected his experience in making the subject more understandable to students. *An Elementary Treatise on Astronomy in Four Parts* was one of the first astronomy textbooks published in America by an American astronomer. Norton's text, concentrating on both mathematical and practical aspects of the subject, was typical of those of the period, but differed in the greater degree to which it utilized illustrations and diagrams and in its more concise language as compared to others. This volume went through four editions, the last being published in 1881 as *Treatise on Astronomy, Spherical and Physical*. While at Yale, Norton authored a second textbook, *First Book of Natural Philosophy and Astronomy* (1858).

Norton's scientific interests extended to thermodynamics and molecular physics. He was elected a member of the American Philosophical Society, the National Academy of Sciences, and a corresponding member of the National Institute for the Promotion of Science.

Gary L. Cameron

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Norwood, Richard

Born **Stevenage, Hertfordshire, England, 1590**
Died **Bermuda, 1675**

Richard Norwood was notable for his works on navigation and surveying. He wrote an autobiographical journal in 1639 in which he described his father (Edward?) as a gentleman who had suffered financial adversity. After Richard's formal schooling ended, he was apprenticed to a fishmonger at age 15. Contact with seafaring men started him on a series of voyages and adventures and initiated his devotion to the study of navigation, which he pursued by studying every book on the subject that came his way. Norwood married Rachel Boughton in 1622; of their four children, their second son, Matthew, followed his father's interests.

In the 17th century, much effort in astronomy and mathematics was motivated by the practical needs of navigation and surveying, areas to which Norwood made notable contributions. He carried out the first survey of Bermuda in 1614/1615, taught mathematics in London from 1627 to 1637, and, in a futile attempt to escape religious strife, returned to Bermuda where he continued teaching. In 1663, Norwood completed a second survey, which still stands as the basis of boundaries on the island.

Besides his journal and surveys, Norwood wrote at least seven books, covering aspects of fortification, mathematics, and navigation. He was arguably the first person to provide, in his *Trigonometrie* of 1631, clear explanations of great circle sailing and how to use logarithms in solving plane and spherical triangles. While this book also contained tables of the declination of the Sun based on tables by Edward Wright and of a few stars precessed from **Tycho Brahe**'s catalog, Norwood's only book dealing specifically with an astronomical topic was *A table of the suns true place ... made according to many exact observations of the Sunne, taken in severall Years last past in the Somer Islands* [Bermuda] (1656).

His very influential *Sea-mans Practice* (1637) contained Norwood's measurement of the length of a degree, or after multiplying by 360, the circumference of the Earth: 25,036 English miles, very close to the modern mean value of 24,873 miles. It stood as the best available value for a long time; **Isaac Newton** used it in the 1713 and 1726 editions of his *Principia*. To arrive at this remarkable result, Norwood measured the latitude of York and London, England, and found the distance between those cities by chaining and pacing, correcting for winding roads, ascents, and descents. The vital implication for navigators was that a nautical mile (1 min of latitude) was not the 5,000 ft. that they had traditionally used but rather 6,120 ft. as Norwood stated, very close to our present-day value of 6,080 ft. For astronomers, knowing the size of the Earth accurately is the first step in measuring extraterrestrial distances.

The fact that three of Norwood's books were reprinted as recently as the 1970s is an indication of the lasting interest he holds for scholars. These and his *Journal* (published in 1945) are accessible primary sources.

Peter Broughton

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Novara, Domenico Maria da

Born **Ferrara, (Italy), 29 July or 1 August 1454**
Died **Bologna, (Italy), 15 or 18 August 1504**

Domenico da Novara was a teacher of **Nicolaus Copernicus**.

Domenico's family name was Ploti; they originated in Novara, a city in northwestern Italy, and later moved to Ferrara in northeastern Italy, where Domenico was born. He obtained both the title of Doctor of Arts and Doctor of Medicine, but we do not know at which university he studied. A possible record of his education is contained in an astrological text ascribed to Dominicus. The author testifies he was a pupil of **Johann Müller** (Regiomontanus), who traveled in Italy between 1460 and 1467 and later between 1472 and 1475, and lived in various Italian cities for long periods, including Ferrara. In any case, da Novara taught astronomy at Bologna University from 1483 till his death.

During this period da Novara was requested to publish prognostications for every year; many of them (in Italian and Latin) have survived and represent the only works we know by him. Apart from the astrological judgments they contain, the interesting parts of these publications are the preambles, where he discusses his scientific and philosophical theories.

The most famous was the prologue for the prognostication of 1489, in which da Novara presented his theory on the shift of the terrestrial polar axis. This was based on the comparison of the latitudes of Cádiz in Spain and several places in Italy, determined in his own time, with those reported in **Ptolemy**'s *Geography*. His conclusions were wrong, because they were based on unreliable data, but they are important because they represent one of the first attempts to suppose an Earth not at rest.

From later sources we know da Novara computed the obliquity of the ecliptic in 1492, obtaining a value very close to the actual one for this year.

Between the end of 1496 and the beginning of 1497, Copernicus registered in the Public Register of the German College in Bologna University. No record of his life in Bologna can be found in Copernicus's works, but **Rheticus** later reported that Copernicus lived in da Novara's house and helped him in his astronomical observations. Three of these observations are indeed reported by Copernicus: the observation of Aldebaran eclipsed by the Moon on 9 March 1497, and the observations of the conjunction of Saturn with the Moon on 9 January 1500 and 4 March 1500.

Giancarlo Truffa

Alternate name

Ploti Ferrariensis

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Numerov [Noumeroff], Boris Vasil'evich

Born **Novgorod, Russia, 17/29 January 1891**
Died **Orel, (Russia), 13 September 1941**

Boris Numerov was one of the principal organizers of Soviet astronomy after the 1917 Bolshevik Revolution. Both a theoretician and a practitioner, Numerov specialized in celestial mechanics, astrometry (positional astronomy), and gravimetry. He was the key Soviet figure in applied celestial mechanics before World War II. His principal legacy was the Institute of Theoretical Astronomy of the Russian Academy of Sciences, which has unfortunately closed very recently. Numerov was elected a corresponding member of the Soviet Academy of Sciences in 1929.

Numerov was a graduate (1913) of Saint Petersburg University and for a short time (1913–1915) a supernumerary astronomer at the Pulkovo Observatory. Like the renowned astronomer Sir **Arthur Eddington**, Numerov debuted as an observer with a zenith-telescope. From 1917 until his arrest in 1936, Numerov taught at Leningrad University where he was named a professor in 1924. In 1919, he founded and operated the Computing Institute, which, in 1923, was merged with the Astronomical–Geodetical Institute, also initiated by Numerov, to become the Leningrad Astronomical Institute. In 1943, the latter was transformed into the Institute of Theoretical Astronomy – the principal center for celestial mechanics research in Russia. Apart from his other duties, in 1926/1927, Numerov was the director of the Voeikov Main Geophysical Observatory and, in 1931–1933, chief of the Department of Applied Mathematics within the State Optical Institute. He fostered the development of the Abastumani Astrophysical Observatory in Georgia.

Numerov arranged computations for the *Astronomicheskii Ezhegodnik SSSR* (USSR Astronomical Almanac; first issued in 1921), which provided annual information on astronomical events of all kinds. He produced a number of astronomical tables and handbooks. He paid full attention to the data obtained by astrometrical and gravimetrical instruments and strove to improve them. Numerov performed significant applied research, including gravimetrical measurements to identify potential ore and oil deposits. He initiated the creation of an annual ephemeris of minor planet elements and positions, published to this day. Numerov also developed a method for using minor planet data to determine the Equator and equinox for star catalogs. His disciples worked in many institutions of the then USSR.

Internationally known for his scientific and organizational activities, Numerov was arrested (along with many other Leningrad astronomers, including Pulkovo's director, **Boris Gerasimovich**), at the beginning of Stalin's Great Terror. Imprisoned and tortured as a supposed saboteur and fascist spy, Numerov was executed by a firing squad in prison, before the Nazis captured the city. Many aspects of Numerov's heritage are visible even today. Minor planet (1206) Numerowia was named for him, as is a crater on the farside of the Moon.

Alexander A. Gurshtein

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Nunes, Pedro

Born **Alcácer do Sal, Portugal, 1502**
Died **Coimbra, Portugal, 11 August 1578**

Pedro Nunes is chiefly known for his theoretical work on celestial navigation, and his translations into Portuguese of works by **John of Holywood** (Sacrobosco) and **Ptolemy**. Nunes was the son of Jewish parents converted to Christianity. During his youth, Portugal was a leader in voyages of exploration and discovery; in the year of Nunes's birth, Vasco da Gama undertook his second voyage to India, and Brazil had already been discovered 2 years earlier. In 1517, Nunes started his university studies in humanities, philosophy, and medicine at the University of Lisbon, and, by 1521/1522, he had gone to Salamanca to study at the university there. In Salamanca Nunes married Dona Guiomar Aires in 1523, and they had six children (two boys and four girls).

Nunes returned to Portugal in 1524/1525, and on 16 November he was named cosmographer of the kingdom. At that time he was Doctor of Medicine. Nunes's nomination was due to his wide knowledge of astronomy – the course of medicine included studies of mathematics and astronomy, required for the practice of astrological medicine.

At the University of Lisbon, Nunes was in charge of lecturing on the subjects of moral philosophy, logic, and metaphysics. In 1532, he went to Évora as tutor of the Infants D. Luís and D. Henrique, future cardinal and king of Portugal. Another pupil was D. João de Castro, who would become one of the greatest Portuguese navigator pilots and was the future Viceroy of India. On 16 October 1544 Nunes was named lecturer of mathematics at the University of Coimbra, where he had been transferred from Lisbon in 1537. He lectured on that subject until his 25th year jubilee in 1562.

On 22 December 1547, Nunes was named First Cosmographer of the kingdom. He became so famous that in the year before his death, he was consulted by Pope Gregory XIII about his project of calendar reform. Some studies about Pedro Nunes state that he had been **Christoph Clavius**'s professor when the latter attended classes at the College of Arts at Coimbra in 1556/1557, but such information is erroneous.

Nunes's work is vast, not just limited to mathematics and the nautical sciences; he also wrote poetry. Nunes was considered the greatest Portuguese navigator of the Renaissance, and yet he did not set foot overseas. His fame was due to his scientific work, mainly nautical. His worries about the practical workability of knowledge showed a preponderance of the utilitarian mind over the speculative one. To him, "science" had its sphere of action limited to the "certain and true" things. This practical aspect is seen in the style Nunes used to write out his texts and notes, endowed with great clarity and rigor concerning the presentation of rules and the demonstration of theorems.

Nunes's work can be divided into two major groups: The first is translations and annotations, the second, original works.

Nunes's *Tratado da Sphera com a Theorica do Sol e da Lua* and the *1° Livro da Geografia de Ptolomeu Alexandrino* include the annotated translations of three works. The *Tratado da Sphera* is the translation of the book of Sacrobosco with his own notes attached; the *Theorica do Sol e da Lua* comprises the translation of the first three subjects of **Georg Peurbach**'s *Theoricas dos Planetas*, with 17 added notes of his own. The third translated work is the first book of geography by Ptolemy, also with notes by Nunes.

After some questions posed by the Portuguese navigator Martim Afonso about the direction and course line of a ship at sea, Nunes was the first to develop the theory of loxodromics, demonstrating that the line drawn by a ship at the sea's surface, when it cuts all the meridians on the same oblique angle, is not a great circle, as they used to think, but a spheric spiral that rounds the Earth's poles an infinite number of times. He also demonstrated that the only circular course lines are the meridians and the parallels that equal the angles of the course of 0 and 90°. Consequently, he wrote *Tratado sobre certas duvidas da navegação que Martim Afonso propoz ao Author*, as well as *Tratado em defensão da Carta de marear com o regimento da altura*, where Nunes also demonstrated a new way to calculate the distance to the pole.

One of Nunes's masterpieces is *De Crepusculis Liber unus; Allacen Arabis vetustissimi Liber de Crepusculis*. In this work he solved the problem of how to find the day with the smallest twilight, and also presented a method for measuring angles with more accuracy. At that time, in order to measure the altitudes of the stars and planets, astronomers used the cross-staff, the quadrant, and the plane astrolabe, all of which devices lacked precision. In his work *De Regulis et Instrumentus*, Nunes described his invention thus:

> … due to the smallness of the device, it is not possible to subdivide its parts, therefore it is not possible to estimate the part of the height that should be needed to add to the whole number of degrees. It would be convenient to describe, inside the device's surface area, 44 concentric circles, dividing the external quadrant in 90 equal parts, the closest in 89, the following in 88, and so on, always in the same sequence.

Later, Nunes's idea would be improved by Jacob Curtio and Clavius, but it was Pierre Vernier who made possible the practical workability of this solution to the problem of reading fractions of angles, and whose name is associated with it today.

Fernando B. Figueiredo

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Nušl, František

Born **Jindřichův Hradec, (Czech Republic), 3 December 1867**
Died **Prague, (Czech Republic), 17 September 1951**

František Nušl was one of the founders of modern Czech astronomy. He was the son of Ignác Nušl and Františka Nušlová (*née* Novotna) and was educated at the Czech Charles-Ferdinand University in

Prague (bachelor of philosophy 1905). He and his wife Aloisie (*née* Doležalová) had two sons and a daughter. Nušl taught mathematics and physics at a high school before receiving his Ph.D. and was appointed an associate professor of mathematics at the Czech Technical University, Prague (full professor: 1911). He was director of the National Astronomical Observatory in Prague from 1918 and professor of astronomy at Charles University until his retirement in 1937. Nušl served as president of the Czechoslovak Astronomical Society (1922–1948) and vice president of the International Astronomical Union (1928–1935).

Nušl's work was largely in practical astronomy and construction of astrometric instruments. In 1899, he constructed the first model of a mirror astrolabe with an artificial mercury horizon to measure the time of star transit over the almucantar (parallel of altitude) using the method of equal altitudes. A professional instrument, later called a circumzenithal, was constructed in 1901 in cooperation with Josef Jan Frič, an amateur astronomer, engineer, and owner of a fine mechanics and optics factory in Prague. Nušl used the instrument in a photographic mode in 1907 to measure short-term variations of refraction of light in the atmosphere. He and Frič presented a portable model at the International Union of Geophysics at its 1924 general assembly in Madrid, Spain, and it was later used in international longitude measurements and to determine astronomical coordinates of the Czechoslovak fundamental triangulation network. During the same period, he designed two other less successful instruments with mirrors and mercury horizons: A diazenithal (to measure the time a star crosses a particular azimuth) and a radiozenithal (to measure the time a star crosses a great circle, inclined to the horizon). Nušl also improved the state of micrometers and regulators in use at his observatories, made use of the then new radio telegraphic signals for the time service, and applied the instruments to problems of geodesy.

Beginning in 1898, Nušl assisted Frič in building a private observatory at Ondrejov, near Prague. It was donated to the state in 1928, merged with the National Astronomical Observatory (with Nušl as the first director), and is now the home of the Astronomical Institute of the Academy of Sciences of the Czech Republic. Nušl was also active in visual observations of meteors and in popularization of astronomy and physics. His publications appeared in Czech, German, and French.

Jan Vondrák

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O

O'Connell, Daniel Joseph Kelly

Born **Rugby, Warwickshire, England, 25 July 1896**
Died **Rome, Italy, 14 October 1982**

The O'Connell effect was discovered by Daniel O'Connell, British–Irish director of the Vatican Observatory. It is a variation in the period of eclipsing binary stars. Tidal effects, star spots, circumstellar disks, and other models have been proposed to explain it.

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Odierna [Hodierna], Giovanbatista [Giovan Battista, Giovanni Battista]

Born **Ragusa, (Sicily, Italy), 13 April 1597**
Died **Palma di Montechiaro, (Sicily, Italy), 6 April 1660**

Giovanbatista Odierna was an early observer of Jupiter and Saturn and one of the first to discover and describe nebulae. He was the son of Art Vita Dierna, who was either a mason or a shoemaker according to different sources, and Serafina Rizo. Very probably, his family lived under inferior, more probably poor conditions. While mostly referred to as Odierna, it seems that the man himself always used"Hodierna" as his name; it is not completely clear why and how he changed the name.

Odierna was self-educated, at least in science. As a young man, he observed the three comets of 1618/1619 (C/1618 Q1, C/1618 V1, and C/1618 W1) from Ragusa, with a Galilean type telescope and fixed magnification 20. He became a Roman Catholic priest and was ordained at Syracuse, Sicily, in 1622. From 1625 to 1636, Odierna served as a priest in Ragusa, and taught mathematics and astronomy at his hometown.

Odierna was an enthusiastic follower of **Galileo Galilei**. In 1628 he wrote the *Nunzio del secolo cristallino*, an appraisal of Galilei's *Siderius Nuncius*. Odierna was particularly impressed by Galilei's resolution into stars of the Milky Way and the "nebulae" like Praesepe; this generated a lifelong interest in nebulae, although most of his astronomical work concentrated on the bodies of the Solar System.

In 1637, Odierna followed Carlo and Gulio Tomasi, the Dukes of Montechiaro, to the newly founded Palma di Montechiaro. They gave him a house and a piece of land on which to live and funded his publications; he served them first as a chaplain and then as a parish priest. In 1644, Odierna earned a doctorate in theology. In 1645, he was named archpriest, in 1655 court mathematician.

Besides his duties as priest, Odierna practiced astronomy, as well as natural philosophy, physics, botany, and other sciences. He studied light passing through a prism and formulated a vague explanation of the rainbow. He developed an early microscope and studied, for example, the eyes of insects and the fangs of vipers. He also studied meteorological phenomena.

Odierna's contributions to astronomy, though interesting and remarkable in particular if one takes his isolated life into account, have had at best little impact, because his publications had only limited circulation and were hardly known outside Sicily. Therefore, standard tracts on the history of astronomy rarely spend more than a few lines on this early priest astronomer. Also, his astronomy always tended to be mixed up with astrology. In 1646 and 1653, Odierna observed Saturn and created drawings showing the planet with its ring quite correctly; he had a short correspondence with **Christiaan Huygens** on this subject around 1656. His *Protei caelestis vertigines sev. Saturni systema*, published in 1657, is among his best-known publications.

In 1652, Odierna observed eclipses of Jupiter's satellites, as well as the passages of their shadows over the disk of the planet. In 1656, he published in the *Medicaeorum Ephemerides*, probably his best-known work, the first published ephemerides of the Galilean satellites, based on an improved theory of the motion of Jupiter's moons by the contribution of three types of periodic disturbances – analogous to contemporary planetary theory. In his 1656 *De Admirandis Phasibus in Sole et Luna visis*, Odierna gives a treatise on the appearance of the Sun and the Moon, including sunspots and eclipses.

Perhaps Odierna's most interesting work is his 1654 *De systemate orbis cometici; deque admirandis coeli characteribus*, which unfortunately was forgotten and ignored until it was recovered by G. Serio *et al.* (1985). Odierna thought there were profound differences between comets and nebulae: Because of the motion and changing appearance of comets, he thought them to be made up of a more terrestrial matter, while nebulae should be made up of stars, and thus *Lux Primogenita*. In the first part he follows Galilei's ideas on comets. In the second, more interesting part, he describes and lists 40 nebulae he had observed, with finder charts and some sketches, which Odierna classifies according to their resolvability into stars as Luminosae (star clusters to the naked eye), Nebulae (appearing nebulous to the unaided eye, but resolved in his telescope), and Occultae (not resolved in his telescope). About 25 of them can be identified with real deep-sky objects (mostly open clusters); the others are either asterisms or insufficiently described for identification.

Today, the original discovery of between ten and 14 deep-sky objects, and two independent rediscoveries (of the Andromeda and the Orion Nebula), are attributed to Odierna. The formal list includes: the Alpha Persei cluster (Melotte 20), NGC 6231, M6, NGC 6530, M36, M37, M38, M47, M41, and NGC 2362, as well as probably M33, NGC 752, M34, and NGC 2451 and perhaps NGC 2169 and NGC 2175. Odierna ‘s deep-sky discoveries occurred within a larger project he endeavored, compiling a sky atlas, *Il Cielo Stellato Diviso in 100 Mappe*, a work he never completed.

Hartmut Frommert

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Oenopides of Chios

Born **Chios, (Khíos, Greece), *circa* 490 BCE**
Died ***circa* 420 BCE**

Little is known about the life of mathematician and astronomer Oenopides; his place of birth in Chios is reasonably well documented, and there is circumstantial evidence indicating that he spent time in Athens as a young man.

Oenopides made a number of contributions to mathematics and astronomy. He is thought to have settled on the value of 24° as an estimate for the angle that the ecliptic makes with the celestial equator. (**Eudemus** attributed the concept of the ecliptic to Oenopides, although the Babylonians were aware that the apparent path of the Sun through the zodiacal constellations was inclined to the plane of the Equator.) This is uncertain, because there is no explicit reference to this estimate in the Greek sources; however, **Proclus**, discussing Euclid IV, 16, says that the construction of a 15-sided regular polygon within a circle was included because it is useful in astronomy. (The 360° division of the circle was not yet developed as a common usage, and this figure would generate central angles of 24°.) It is possible that Oenopides originated both the estimate (24°) and the construction of the 15-sided figure. **Plato** appears to allude to Oenopides's research on the ecliptic when he includes him in the *Erastae*.

Oenopides seems to be best known for his research on the Great Year. As knowledge of astronomy progressed in classical times, this concept came to refer to the period after which the motions of the Sun, the Moon, and all of the planets would repeat themselves. Aelian and **Aëtius** give Oenopides credit for an estimate of 59 years for the period of the Great Year; it is not clear which, if any of the planets were intended to be accounted for within this period. It seems likely that Oenopides made his estimate based on a lunar month of roughly 29 and one-half days, and a 365-day solar year. This could quickly lead to the ratio of 730 lunar months for every 59 years; since 59 is a prime number, it would then provide a possible figure for the Great Year period. It appears that Oenopides attempted to confirm this estimate based on observations throughout his life.

Oenopides's contributions to mathematics may have a wider significance as well. In his commentary on Euclid's *Elements*, Proclus cites Oenopides as the originator of two theorems (I.12 and I.23), both having to do with elementary constructions. Ivor Bulmer-Thomas in the *Dictionary of Scientific Biography* makes the interesting conjecture that "it may have been [Oenopides] who introduced into Greek geometry the limitation of the use of instruments in all plane constructions … to the ruler and compass." This may be significant for astronomy because it suggests that Oenopides developed a serious interest in the methodology of mathematics, with a particular focus on the distinctions between theoretical and applied mathematics.

Kenneth Mayers

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Offusius, Jofrancus

Born **Geldern, (Nordrhein-Westfalen, Germany), before 1530**
Died **possibly Paris, France, after 1557**

Astrologer Jofrancus Offusius is an almost unique example of a scholar in the French cultural area who studied the technical details of **Nicolaus Copernicus**'s *De revolutionibus* in the first two decades after its publication in 1543. Offusius's examination of Copernicus's ideas is well documented by the annotations and by appended manuscript pages in his copy of *De revolutionibus* (now preserved in the National Library of Scotland), and his influence is attested by eight further copies of his annotations made by his students or by their students. The longest annotation occurs in the most complex part of the book, where Copernicus deals with the lunar parallax. While his major criticism there is marred by an erroneous start, Offusius's series of short corrections to the later part of the paragraph demonstrate that he could handle the detailed calculations with more accuracy than Copernicus did.

Very few details are known regarding Offusius's life. **Girolamo Cardano** refers to Franciscus Offusius Geldrensis when discussing cipher codes in his *De rerum varietate* (Basel, 1557), from which we deduce his place of birth. Offusius records in his *De revolutionibus* that he had been in Seville, Spain in 1550; later he was in England for a year under the patronage of the Elizabethan *magus* **John Dee**. In 1557, Offusius published in Paris *Ephemerides* for that year based on calculations derivative from Copernicus's work. It was during his time in Paris that he must have operated an atelier for astronomy students including Jean Pierre de Mesmes, who worked with Offusius for some time between 1552 and 1557. In one of his own annotations, de Mesmes referred to his teacher as "not one of the common astronomers." Circumstantial evidence suggests that the 16th-century central European astronomers **Paul Wittich** and/or **Tadeá Hájek z Hájku** saw Offusius' own annotated copy, for Wittich's own annotations show influence from that specific copy and include the name "Jofrantius" in the margin.

Pontus de Tyard, a 16th-century astronomer and philosopher, mentions meeting Offusius in Dieppe, presumably in 1556, and remarked that his tables (ephemerides) were "different from all the rest." In the preface to his *Ephemerides*, Offusius indicated that he had worked on planetary influences for 14 years, and had become increasingly dissatisfied with the *Alfonsine Tables,* which he rejected as worthless. Apparently for January 1557, Offusius used the Copernican *Prutenic Tables*, but for the remainder of the year he employed some not very successful modification of them. In the book's preface, he announced that Mercury would twice pass in front of the Sun that year, predictions that proved quite wrong.

After 1557 Offusius disappeared from the scene, but in 1570, his widow published *De divina astrorum facultate*, a book that deals with planetary distances, a topic rarely addressed between Copernicus's *De revolutionibus* and **Johannes Kepler**'s *Mysterium cosmographicum* of 1596. The preface to the book is dated 1556. Using a geocentric framework, Offusius attempted to find an esthetically pleasing principle to establish the planetary distances to be used for his theory of astrological aspects. He worked within the traditional notions that the Sun was 19 times further than the Moon, and that Saturn was about 19 times farther than the Sun. He then had to insert two other planets within each of these two intervals, which he achieved with proportional spacing so that the ratio of the distances of each pair was the same, 8/3 (nearly the cube root of 19). His starting point must have been the solar distance of 576 terrestrial diameters, the square of 24, whose beauty pleased him greatly. In an obscure way Offusius argued that his proportions were related to numbers associated with the Platonic polyhedra, a feature that **Tycho Brahe** commented on favorably and that no doubt helped persuade him to take seriously Kepler's later use of these polyhedra to explain the spacing of the planets in the Copernican system.

Owen Gingerich

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Öhman, K. Yngve

Born **Stockholm, Sweden, 27 March 1903**
Died **Lund, Sweden, 17 June 1988**

Yngve Öhman, the founder of Swedish solar astronomy, designed, built, and used the first narrow-band interference filter (the birefringent quartz polarizing monochromator) useful for monitoring solar activity. The son of Karl E. and Ida (*née*) Cassel Öhman, he saw comet 1P/Halley at age seven and built a small telescope by 17. Öhman began studies at Uppsala University in 1922, receiving a Ph.D. in 1930 for work with **Bertil Lindblad** on luminosities and distances of stars. Other important early influences at Uppsala were **Östen Bergstrand**, **Hugo von Zeipel**, and **Knut Lundmark**. The thesis work was done partly with spectrograms taken at the Mount Wilson Observatory, California, by **Milton Humason** and **Paul Merrill** and brought back to Sweden by Lindblad. Öhman recognized that the spectral absorption features due to CaH at 6365 Å and to neutral calcium at 4227 Å were much stronger in dwarf stars than in giants of the same (relatively low) temperature, and so could be used to estimate stellar intrinsic luminosities (and so stellar distances) even in quite low-dispersion spectra.

Öhman held positions at Stockholm Observatory most of his life (1930–1938 as assistant or observer, with a year away at Mount Wilson in 1933/1934; as observer at the Saltsjöbaden Observatory of Stockholm 1939–1953; and as occupant of a personal chair of astrophysics 1953 to 1968, when he retired). He also spent brief periods at Uppsala, Boulder, Colorado, USA and Mount Wilson again. As early as 1929, Öhman had predicted that the light from solar prominences and from comets should be polarized because of fluorescence, and was eventually able to verify this in both cases (comet C/1940 R2, and the solar case within days of commissioning his new filter).

Robert Wood first showed that one could separate out a single spectral feature using a sandwich with a quartz slab between two polarizing filters. It is a property of quartz that two perpendicular polarizations of light travel at different speeds, and so arrive at the other side of the slab out of phase, producing an interference pattern, in which some wavelengths come through at almost full strength and others are not transmitted at all. Öhman extended this idea to a "layer cake" with four quartz slabs (relative thickness 1:2:4:8, all of order millimeters) and five films of Polaroid around and between them. The slab thicknesses were chosen so that the 6563 Å wavelength of hydrogen came through, and the next transmission peaks were nearly 1000 Å away and so could be blocked by ordinary colored glass filters. Such a device picks out a bandwidth of about 50 Å. Thus it is not as good a monochrometer as the spectroheliograph of **George Hale** and **Henri Deslandres**, but has the enormous advantage that you can image the whole Sun at once, instead of one thin slice at a time. The filter can be tuned to somewhat different wavelengths by tilting it, and it automatically acts as a polarimeter as well. Such devices are widely used in solar observatories today. The idea had occurred somewhat earlier to **Bernard Lyot**, but he had not yet constructed a device at the time Öhman started using his.

Öhman's main field was observational solar astronomy. He developed solar patrols. At first, these observations were performed at the Satlsjöbaden Observatory. However, because of the weather conditions at Stockholm, setting up a solar observatory elsewhere was the goal. Together with **Donald Menzel**, Öhman first studied the conditions for solar research in northern Sweden. The region around Abisko research station was a better site than Stockholm, and for a while the alternative of Abisko seemed viable, but more favorable conditions were found on the island of Capri, where a station for solar research was established by Öhman and the Royal Swedish Academy of Sciences. Öhman's interest in Capri as a site for solar observations had been aroused when Axel Munthe's villa *San Michele* had been willed to the Swedish state and opened for use by scientists and artists. Öhman also developed good contacts with the foundation Centro Caprense di Vita e di Studi, from which initial support was given.

Regular observations at Capri began in the summer of 1952. Soon the station ran a continuous solar flare patrol. Flares, prominences, and other solar phenomena were studied with photometric and spectroscopic methods. Several Swedish astronomers worked at the Capri station as assistants, gaining important training in solar observation techniques. The best known of Öhman's students in solar and stellar astronomy are Jan Stenflo, Kirsten Fredga, and Dainis Dravins.

Öhman's involvement in international astronomy began as early as 1938, when he chaired the local organizing committee for the 1938 general assembly of the International Astronomical Union [IAU] in Stockholm, and he was president of an IAU solar commission in 1952–1955. Both Öhman and the Capri observatory were active in the International Geophysical Year (1956–1958), and he served on committees for the European Space Research Organization and the journal *Solar Physics*. The Royal Swedish Academy of Sciences elected him to membership and awarded one of the several medals Öhman received for his contributions to international solar astronomy.

Öhman's interests were not confined to solar astronomy: The construction of scientific payloads for use on sounding rockets, the influence of geomagnetic storms on power distribution systems, solar energy, and other alternatives to fossil fuels were only some of the fields in which he worked. He held several patents. Öhman's archive shows that he was active with scientific and technological questions up until his death.

Öhman's papers are at the Center for the History of Science, Royal Academy of Sciences, Stockholm.

Gustav Holmberg

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Olbers, Heinrich Wilhelm Matthias

Born **Arbergen near Bremen, (Germany), 11 October 1758**
Died **Bremen, (Germany), 2 March 1840**

Credited with the independent discovery of four comets and two of the first four asteroids discovered, physician Heinrich Olbers was one of the leading astronomers of the early 19th century. Functioning as an amateur in his private observatory, Olbers was widely respected by his astronomical colleagues. Though he neither discovered nor resolved Olbers' paradox, it is invariably given his name.

Young Olbers lived with his father, Johann Jürgen Olbers, a Protestant minister, and 15 brothers and sisters. His interest in astronomy originated at the age of about 14, but due to a limited curriculum in the exact sciences at the humanistic Gymnasium in Bremen, he was forced to study mathematics on his own. Olbers's first attempts in astronomy were the calculation of the solar eclipse of 1774, the calculation of the orbit of comet C/1779 A1 (Bode) from his own observations (in 1779), and a discovery of a comet (C/1780 U1, independently discovered by Jacques Leibax Montaigne (1716–1785?) of Limoges, France. While studying medicine at Göttingen University, Olbers also attended lectures in mathematics and physics. In medicine he specialized on ophthalmology; after graduation in 1781 he moved to Vienna, where he spent one year practicing in hospitals. During that year Olbers also visited the Vienna Observatory and enjoyed life in the aristocratic society.

Toward the end of 1781 Olbers opened a private ophthalmologic practice in Bremen and soon attracted many patients. He slept only 4 hours a day, reserving his nights for astronomical observations. During the next 30 years he was able to practice medicine while working in astronomy at a level comparable to the best professional astronomers. In 1820 Olbers decided to devote all his time to astronomy, so he closed his medical practice.

Olbers converted one part of the second floor of his Bremen house into an observatory, the equipment included movable telescopes and comet seekers made by such renowned instrument producers as Dollond and Fraunhofer. By fortunate chance, one of the best-equipped private observatories in the region was in nearby Lilienthal. After 1786, Olbers collaborated with its owner, **Johann Schröter**. **János von Zach** visited Olbers in Bremen as well as the Lilienthal observatory in September 1800 and published a description of both observatories in his journal *Monatliche Correspondenz* in 1801. During that visit, on 20 September, Schröter, Zach, Olbers, **Carl Harding,** and about 20 other outstanding astronomers from Germany and the rest of Europe founded *Vereinigte Astronomische Gesellschaft*, the first astronomical society in the world.

When Olbers discovered the comet of 1796 (C/1796 F1), he elaborated a new method for calculating its parabolic orbit using only a few observed positions. The methods developed by **Joseph-Jérôme de Lalande** and **Pierre de Laplace**, common at that time, were based on subsequent approximations, and lead often to erroneous results. However, Olbers's method was much simpler, satisfactorily precise, and reliable. Zach published it in Weimar (1797) under the title "Üeber die leichteste und bequemste Methode, die Bahn eines Kometen aus einigen Beobachtungen zu berechnen." The Olbers method was widely adopted and used throughout the 19th century. Olbers computed about 20 orbits of comets, including an orbit for comet C/1798 X1 (an independent discovery by Olbers, but credited to **Alexis Bouvard**), as well as for the periodic comet 13P/1815 E1 that he discovered.

When the first-known minor planet (1) Ceres disappeared behind the Sun, astronomers were not successful in finding it when it emerged from the Sun's glare a few months later. **Carl Gauss** developed a new method of determination of an elliptic orbit, and computed the expected positions. On 1 January 1802, Olbers found Ceres near the place given by Gauss, exactly one year after the original discovery of Ceres by **Giuseppe Piazzi** in Palermo. As a result, a close friendship developed between Olbers and the younger Gauss. Olbers discovered two other minor planets – (2) Pallas in 1802 and (4) Vesta in 1807 – the third, (3) Juno, was found at Lilienthal by Harding.

In 1812, Olbers suggested that a comet's tail was composed of particles driven away from the nucleus of the comet in the anti-solar direction by repulsive forces from the Sun. Olbers supposed that the forces were electrical in nature. He also offered the insight that the direction and orbital speed of the comet as well as the gravitational influence of the Sun all had a marked influence on the morphology of the comet's tail.

The question "Why the sky is dark at night?" had earlier been raised by **Johannes Kepler**. He pointed out that in the infinite space, uniformly filled by stars, every line of sight had to end on a surface of a star, so that the sky had to appear as bright as the stellar surface, *e. g.*, as the Sun. Like **Edmund Halley** and **Jean Loys de Chéseaux**, Olbers came independently to the same conclusion. He published it in 1823 under the title "Über die Durchsichtigkeit des Weltraums" in *Berliner astronomisches Jahrbuch fuer das Jahr 1826*. Since that time the problem has been referred to as Olbers' paradox. The contemporary (not correct) solution assumed slightly absorbing matter dispersed between the stars, but the correct solution (the finite age and energy density of the Universe) was later given as a part of relativistic cosmology.

In 1837, Olbers pointed out, based on his study of the Leonid meteor showers of 1799 and 1833, that maxima in the strength of that shower might occur on intervals of 3, 6, or 34 years and predicted another great storm in 1867. However, though he studied other celestial phenomena, Olbers's main interest continued to be comets. His preoccupation with the subject caused him to assemble one of the finest libraries on the history of astronomy of its time. With a particular emphasis on cometography, the Olbers library was thought to be "essentially complete" and formed a valuable addition to the library of the Pulkovo Observatory when purchased by **Friedrich Struve** from the Olbers estate.

Olbers himself saw his major contribution to astronomy in the fact that he influenced the young **Friedrich Bessel** (later director of the observatory in Königsberg) to enter a career as a professional astronomer. Bessel's interest in astronomy was aroused after listening to Olbers's lectures. Later, after meeting Olbers on the street in 1804, Bessel showed him his calculations for the orbit of Halley's comet (IP/Halley) based on **Thomas Harriot**'s observations in 1607. Impressed by the young man's self-taught mathematical ability, Olber's suggested some additions and arranged to have the computations published.

In two marriages, Olbers was the father of a daughter and a son. His first wife, Dorthea Köhne, died while giving birth to their daughter in 1786, only a year after their marriage. Olbers remarried in 1789, and Anna Adelheid Lurssen gave birth to a son. Anna died in 1820.

Martin Solc

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Olcott, William Tyler

Born **Chicago, Illinois, USA, 11 January 1873**
Died **George's Mills, New Hampshire, USA, 6 July 1936**

Tyler Olcott founded and nurtured the American Association of Variable Star Observers [AAVSO], served as its secretary for nearly 25 years, and wrote a number of popular books on astronomy.

Olcott, the son of William Marvin and E. Olivia (*née* Tyler) Olcott was raised in Norwich, Connecticut, in the ancestral Tyler home in which he lived for his entire life. Educated at Trinity College, Hartford, Connecticut, Olcott studied at the New York Law School. Though admitted to the state bars in New York and Connecticut, he never practiced law as a career. Olcott married Clara Hyde of Yantic, Connecticut, in 1902; they had no children.

Olcott's introduction to astronomy occurred during a 1905 summer vacation, and he was instantly captivated by the night sky. As he taught himself the stars and constellations he wrote a book on the subject of the naked-eye sky, *A Field Book of the Stars* published in 1907. This was followed by the acquisition of a small telescope with similar results: *In Starland with a 3-inch Telescope*, reflecting his deepening appreciation of the night sky, was published in 1909. After acquiring skills with the telescope, Olcott sought out an application of those skills in the service of astronomy. He found an ideal application in variable star astronomy as he chanced upon a presentation on the subject at a meeting of the American Association for the Advancement of Science. There, he heard **Edward Pickering** describe a scientific need for amateur observers. When Olcott wrote to Pickering asking for more information, the Harvard College Observatory [HCO] director dispatched one of his staff, **Leon Campbell,** to Connecticut to train Olcott and deliver the necessary charts and reporting forms to him. Olcott was so delighted with the experience that he wrote an article describing both the techniques and the need for observers for *Popular Astronomy* and volunteered to facilitate the work of other interested amateur observers. That invitation led Frederick Leonard (1896–1960) to recruit Olcott as the variable star section leader for the Society for Practical Astronomy [SPA]. In addition, with encouragement from Pickering, Olcott undertook the formation of the AAVSO in 1911 and within a year had resigned from the SPA.

From 1911 until his death, Olcott voluntarily served as the recording secretary of the AAVSO and in various other capacities, corresponding with amateur and professional astronomers and prospective new members. He traced and distributed hundreds of variable star charts, instructed observers, acted as liaison between the variable star observers and HCO, compiled AAVSO variable-star observations and notes for use by Pickering and for publication each month in *Popular Astronomy*, and gave numerous public talks on astronomy and variable star observing. In the process Olcott established contacts with noted astronomers at home and abroad.

Olcott published the AAVSO's initial report of 208 observations in the December 1911 issue of *Popular Astronomy*. By the end of its first year the AAVSO had published over 6,000 observations of variable stars in *Popular Astronomy*. From that point on, the number of observations being sent to the AAVSO each year rose dramatically: to 11,600 in 1912; 17,400 in 1917; 19,300 in 1921; and 26,900 in 1924. Under Olcott's guidance, the AAVSO grew very rapidly from a handful of amateur and professional observers in 1911 to about 480 observers in 1936. By the time Olcott died, the AAVSO was receiving nearly 55,000 observations per year.

With rapid growth from 1911 through the 1920s and 1930s, and under the guidance and encouragement of Olcott, the AAVSO membership gained a strong sense of identity and personality. Olcott organized the AAVSO's first regular annual meeting at HCO in November 1915. In October 1918, the AAVSO was incorporated under the laws of the Commonwealth of Massachusetts. HCO then provided a room for the AAVSO's headquarters, and the organization continued to grow. United by their love of astronomy, telescope making, and variable star observing, the AAVSO members' common interest was strengthened by their sharing the common purpose and scientifically important goal of providing researchers with long-term variable star measurements in a reliable and efficient way. The AAVSO is now the largest variable star organization in the world, receiving, processing, and disseminating some 400,000 variable star observations each year, and maintaining an international database that now contains over 11 million observations of variable stars.

Olcott was a life member of the American Astronomical Society, the British Astronomical Association, and the Société Astronomique de France. He was made a fellow of the Royal Astronomical Society of Great Britain, and a fellow of the American Association for the Advancement of Science. He was also appointed to two terms as a member of the Visiting Committee of the Department of Astronomy of Harvard University.

The Field Book of the Skies (first published in 1929) became widely known as the definitive handbook for amateur astronomers, and was published in revised editions after Olcott's death.

The AAVSO council presented, posthumously, the Merit Award of The American Association of Variable Star Observers – the association's highest honor – to William Olcott as "the Founder and Life Secretary of our Association whose words and writing and patient guidance have led many to know and love the stars."

Michael Saladyga

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Olivier, Charles Pollard

Born **Charlottesville, Virginia, USA, 10 April 1884**
Died **Bryn Mawr, Pennsylvania, USA, 14 August 1975**

Charles Olivier contributed to several fields of astronomy: In meteors, he corrected an erroneous belief about meteor shower radiants, and established and guided the American Meteor Society [AMS] for over six decades. He also discovered and studied double stars and made invaluable contributions to the standardization of variable – star visual photometry.

The Olivier family lived in Charlottesville, the site of the University of Virginia. Olivier's parents, George Wythe and Katharine (*née* Pollard) Olivier, owned the University Book Store, purchased with the proceeds of her family estate, and operated a boarding house in their home. Katharine had been raised in the surrounding Albemarle County, and the couple knew most of the university faculty well.

A year before Charles' birth, the university dedicated the Leander McCormick Observatory and its 26-in. Alvan Clark refractor. **Ormond Stone**, director of the observatory and a frequent guest at the Olivier home, encouraged young Olivier to become an astronomer. While still a boy, he eagerly learned how to use the Clark refractor and smaller observatory instruments.

Olivier accompanied the Leander McCormick Observatory's staff to Scottsville, Virginia, in an attempt to photograph the 1899 Leonid meteor shower, his first scientific expedition, and later to Winnsboro, South Carolina, for the 28 May 1900 solar eclipse. During the summer of 1901, Stone employed Olivier to measure stellar magnitudes in variable star fields using a wedge photometer.

While an undergraduate at the University of Virginia (1901–1905), Olivier published variable star observations and meteor shower reports in *Popular Astronomy*. In August 1905, two months after he earned his BA degree, Olivier volunteered as a member of a United States Naval Observatory [USNO] solar eclipse expedition to Daroca, Spain. While there, he met Samuel Mitchell, who would later play an important role in his career. Back in the United States, Olivier began graduate work at the University of Virginia, supported by a Vanderbilt Fellowship, earning a master's degree in astronomy in 1908.

Conducting graduate research at the Lick Observatory from July 1909 to December 1910, Olivier studied stellar spectra and acted as **Heber Curtis**'s assistant in an apparition-long study of comet 1P/Halley. He published double star measurements, a report about the 1909 Perseid meteor shower, and a photographic report about the great January comet C/1910 A1 (with **Paul Merrill**); he also demonstrated that the η Aquarid meteors are likely debris from Halley's comet based upon their orbital similarities.

Olivier earned his Ph.D. in astronomy from the University of Virginia in June 1911. His dissertation, "175 Parabolic Orbits and other Results Deduced from Observations of 6200 Meteors," was drawn mainly from his personal observational data. One of Olivier's important conclusions in the dissertation attacked a notion prevalent in the early 20th century, advanced by **William Denning**, that meteor radiants were stationary in the sky and were intermittently active for periods of days to months. Olivier argued that due to orbital motions of the Earth and the meteor streams this was impossible. He used his own meteor plot data to demonstrate that radiants actually move against the background sky, and only exist for a few days. Over a period of 20 years beginning with his 1911 dissertation, Olivier's theoretical and observational arguments demolished the credibility of Denning's stationary radiants.

In 1911, Olivier accepted a position as an assistant professor of physics and astronomy at Agnes Scott College. While there, he volunteered to direct the meteor section of Frederick Leonard's (1896 – 1960) Society for Practical Astronomy, and simultaneously founded the American Meteor Society [AMS], an organization that continues to promote and collect meteor observations to the present day.

During the summer of 1913, Olivier volunteered at the Yerkes Observatory, and then in June 1914 accepted an adjunct professorship at the University of Virginia, where Mitchell had just been appointed director of the Leander McCormick Observatory. During his early career at McCormick Observatory, Olivier contributed to Mitchell's photographic parallax program. When the United States entered World War I, Olivier volunteered but was disqualified from service on physical grounds, and instead was appointed to the Scientific Staff of the Aberdeen Proving Grounds in Maryland. His supervisor from October 1918 to January 1919 was **Forest Moulton** who assigned Olivier the problem of adapting astronomical photographic techniques to the task of finding cannon shell burst ranges at night. After World War I, Olivier collaborated with Mitchell and Harold Lee Alden (1890–1963) on the visual photometry of variable star fields, and continued his earlier work measuring parallax plates, from which he also discovered a number of new double stars. By the end of his life, Olivier claimed discovery of 198 new double stars.

Olivier married Mary Frances Pender on 18 October 1919. They had two daughters, Alice Dorsey and Elise Pender Olivier during their 15-year marriage.

Olivier obtained leave from his faculty and observational duties from October 1923 to July 1924 to do library research at the USNO in Washington. The product of this work was his first book, *Meteors*, published in 1925. Mary Frances helped him prepare the text for publication. The book, dedicated to Olivier's father who died in 1923, included a comprehensive review of meteor observation history, techniques of meteor observation and height determination, the connection between comets' orbits and meteor streams, and meteorites. *Meteors* also continued Olivier's attack on the belief that meteor showers could have long-lasting, stationary radiants. Olivier explained how inappropriate observational and data reduction practices of the past had contributed to that erroneous belief.

Olivier was appointed secretary of the American Astronomical Society's [AAS] Committee on Meteors in 1916. As *Meteors* was going to press 8 years later, Olivier was elected president of the Meteor Commission of the International Astronomical Union [IAU], a position he held for 10 years. In 1927, Olivier was appointed to the IAU's Commission on Double Stars.

In 1928, Olivier became professor of astronomy and director of the Flower Observatory at the University of Pennsylvania. There, Olivier concentrated upon double star measurements and the photometry of variable star fields using the 18-in. Brashear refractor. Olivier supervised the consolidation of the Flower Observatory with the private observatory of Gustavus Wynne Cook (1867–1940), bequeathed to the university. The Cook Observatory included a 28.5-in. Cassegrain reflector and a 15-in. siderostat refractor.

In 1930, Olivier published his second book, dedicated to Mary Frances. Intended as a sequel to *Meteors*, *Comets* was a nonmathematical treatment of what was then known about the origin, physical composition, and visual presentations of various comets, and associated meteor showers. It was based on Olivier's observations since about 1900. He included a chapter about comet collisions with the Earth that anticipated the 1990s popularization of comet catastrophes.

Until its cessation in 1951, Olivier published monthly articles about AMS results in *Popular Astronomy*. Thereafter, he published periodic reports about the society's findings in *Meteoritics* and *Flower and Cook Observatory Publications*. These reports and Olivier's frequent correspondence with AMS observers to suggest observational goals and to praise or cajole the members' participation, were crucial to the vitality of the organization and its longtime productivity. Olivier directed the American Meteor Society from 1911 until 1973, when he selected David Dering Meisel (born: 1940), an AMS member who had become a professional astronomer, as the new executive director.

After Mary Frances Olivier died in 1934, Olivier raised his daughters by himself, although his sister, Katharine Olivier Maddux, helped him on many occasions. Olivier got married a second time, to Ninuzza Seymour, on 23 October 1936. This marriage ended in a divorce. Olivier did not marry again until 24 July 1950, when he wed Margaret Ferguson Austin who survived him.

Appointed emeritus professor of the University of Pennsylvania in 1954, Olivier continued reducing data produced by members of the American Meteor Society for another 20 years in retirement. In 1974, at age 90, he published his sixth, and final, catalog of hourly sporadic meteor rates.

Olivier was a tireless observational astronomer for 73 years. He also popularized astronomy in newspaper articles, on the radio, and by giving personal presentations to astronomy clubs and community groups. In 1979, the IAU named a lunar crater in his honor.

Richard J. Taibi

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Olmsted, Denison

Born **East Hartford, Connecticut, USA, 18 June 1791**
Died **New Haven, Connecticut, USA, 13 May 1859**

Denison Olmsted was a prominent member of the scientific community in antebellum America. Remembered for pioneering contributions in astronomy, geology, and meteorology, he authored a number of widely used textbooks, including *An Introduction to Astronomy* (1839) and *A Compendium of Astronomy* (1841).

Son of farmers Nathaniel Olmsted and Eunice Kingsbury, Olmsted entered Yale College in 1809 and received his bachelor's degree in 1813. After teaching in New London, Connecticut for two years, he earned a master's degree (1816) from Yale. In 1817, he was appointed to a professorship of chemistry at the University of North Carolina, which he accepted after spending another year of preparation in that subject. A member of the short-lived American Geological Society (founded at Yale in 1819), Olmsted was also instrumental in creating the first state-sponsored geological survey (of North Carolina, 1823–1824), whose reports helped to stimulate other states to conduct geological surveys, starting in the 1830s. In 1825, he returned to Yale as a professor of mathematics, natural philosophy, and astronomy, where he spent the rest of his life. One of Olmsted's most notable students was **Jonathan Lane**.

Olmsted's most notable contributions to astronomy arose from his observations of the 13 November 1833 Leonid meteor storm. He noted that the radiant point, in the sickle of Leo, followed the diurnal movement of the sky. In papers published in the *American Journal of Science and Arts*, Olmsted correctly argued for the shower's origin in interplanetary space, whose meteoric particles traveled along parallel paths and were consumed by fire in the Earth's atmosphere. Along with American astronomers **Edward Herrick** and **John Locke**, he helped to establish the annual nature of these (and other) meteor showers. Olmsted likewise investigated the aurora borealis and the zodiacal light, publishing theories of their purported origins in a related "nebulous body."

Using a small telescope at Yale in 1835, Olmsted and tutor **Elias Loomis** were the first American astronomers to recover comet 1P/Halley at its predicted return.

Jordan D. Marché, II

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Olympiodorus the Younger [the Platonist, the Neo-Platonist, the Great]

Born **Alexandria, (Egypt), 495–505**
Died **after 565**

Olympiodorus the Younger is remembered for having continued the Platonic tradition at Alexandria following the closing of the Greek Academy at Athens by Emperor Justinian of Byzantium in 529. His most influential writings include commentaries on **Plato**'s *Phaedo*, Alcibiades I, Gorgias, and Philebus. Olympiodorus's commentary on Plato's life is most widely cited. Although his authorship of other works is disputed, it is agreed that the extant remains of Olympiodorus are student notes (or copies of notes) taken from his public lectures delivered at Alexandria.

Olympiodorus's works are also valued for information they provide on the life and work of earlier thinkers, notably Damascius, Iamblichus, Syrianus, and significantly, **Ptolemy**. In his *Phaedo*, Olympiodorus offers several valuable sentences, suggesting that Ptolemy lived near Alexandria at Canobus, where he devoted himself to astronomy for 40 years. Further, it was there that he had stone tablets carved to preserve his astronomical discoveries. Details about these inscriptions made at the temple of Serapis have been disputed since the 17th century. Prompted by their interest in Ptolemy, Isaac Vossius and **Ismaël Boulliau** were the first to study Greek manuscript copies of Olympiodorus found in Florence and Paris.

Robert Alan Hatch

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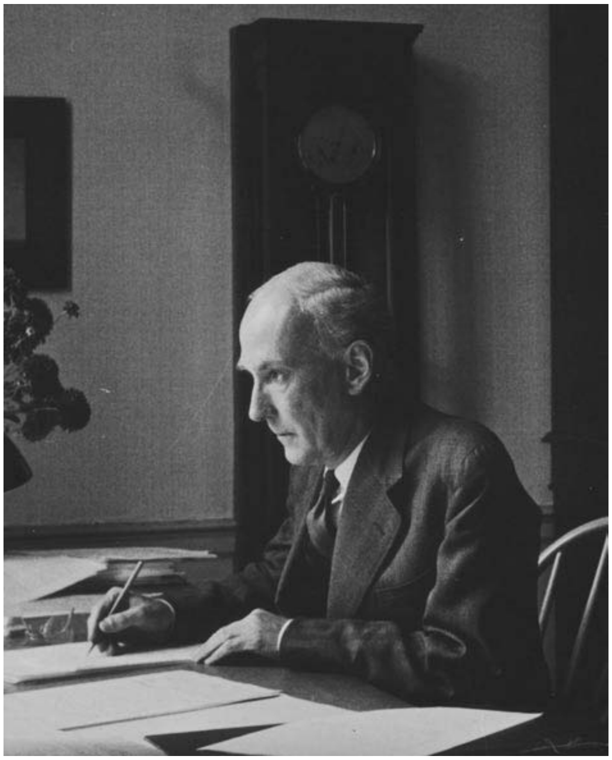
Omar Khayyām

➤ **Khayyām: Ghiyāth al-Dīn Abū al-Fatḥ ʿUmar ibn Ibrāhīm al-Khayyāmī al-Nīshāpūrī**

Oort, Jan Hendrik

Born **Franeker, The Netherlands, 28 April 1900**
Died **Wassenaar, The Netherlands, 5 November 1992**



Dutch astronomer Jan Oort is eponymized in the Oort cloud (of potential future comets on the outskirts of the Solar System), in the Oort constants (of galactic rotation), and in the Oort limit to the density of mass in the disk of the Milky Way Galaxy.

Oort was the son of physician Abraham H. Oort and Hannah Faber. He and his wife, Johanna Maria Graadt van Roggen had two sons and a daughter.

Oort began studies at the University of Groningen in 1917 and was quickly inspired by **Jacobus Kapteyn** to take up astronomy. He completed his doctoral dissertation, on "The Stars of High Velocity," under **Pieter van Rhijn**, following Kapteyn's death and after 2 years at Yale Observatory (1922–1924), where he learned astrometry from **Frank Schlesinger**. Oort's thesis already contained the idea that stars moving faster than about 65 km/sec (an Oort limit) in a particular direction would probably escape from the Galaxy.

Oort spent the rest of his career at the Leiden Observatory and Leiden University as staff member (1924–1930), lecturer (1930–1935), professor extraordinary (1935–1945), full professor and director of the observatory (1945–1970), and in retirement until shortly before his death. The only exception was the period of World War II, 1940–1945, when the university was closed by the occupying forces, and Oort withdrew to a small village in the center of Holland. During his early years at Leiden, Oort was most influenced by **Ejnar Hertzsprung** and **Willem de Sitter**. He, in turn, was formal advisor or mentor to a large fraction of the next two generations of Dutch astronomers.

Jan Oort's approach to science, strongly determined by Kapteyn, was one of close confrontation between observation and interpretation, with a minimum of speculation and, if possible, avoidance of intricate mathematical treatment. He was a man of extraordinary perception, gifted with remarkable intuition for choosing promising courses of research.

Oort received numerous awards, among which were the Kyoto Prize, the Balzan Prize, and the Vetlesen Prize. He was a member of 16 foreign science academies including all the major ones and the recipient of ten honorary degrees.

Oort's scientific activities spanned more than 70 years; his first paper dates from 1922, his last one from 1992. The leading motive in nearly all of his research was the problem of the structure of the Universe at large. In the early 1920s this was still synonymous with the problem of the structure of the Milky Way; only later in the 1920s did it become apparent that the Galaxy is just one among numerous, more-or-less similar, stellar systems. By the time of Oort's last papers, research on the Universe concentrated on the large-scale features in the spatial distribution of stellar systems and on their relation to the initial stages of the Universe.

Rotation of the Galaxy. In a paper of 1927, which brought him international fame, Oort confirmed **Bertil Lindblad**'s hypothesis that the (flattened) Galaxy is a rotating stellar system. He demonstrated by means of available observational data on stellar distances, radial velocities, and proper motions that the bulk of the stars move in nearly circular orbits around a center, the direction of which coincided with the center of the system of globular clusters as proposed by **Harlow Shapley**. The proof lay in the differential motions exhibited by stars located at different distances from this center for which the distance could then be estimated at about 20,000 light years. In a subsequent paper of 1928 on the dynamics of this rotating system, Oort showed that it offered a natural explanation for a variety of phenomena observed earlier, among which were the ellipsoidal velocity distribution of stellar velocities and the peculiar distribution of the directions of the largest stellar velocities – the socalled asymmetry in high velocities. The Oort constants describe this differential rotation in the form of derivatives.

Hidden and observable matter in the Galaxy. In a paper of 1932 Oort derived the strength of the field of force in the stellar system, in particular the force perpendicular to the plane of symmetry (the galactic plane), from a comparison of the velocity distribution of the stars with their density distribution. In the region near the Sun, this force could not be satisfactorily explained by adding the contributions from matter present in the form of stars and interstellar matter [ISM], and Oort suggested the possible existence of an additional component, called "hidden matter" or "dark matter." In his George Darwin Lecture in 1946 he discussed the physics of the ISM: the formation of dust particles from the gaseous medium, the interaction with hot stars, and possible mechanisms of star formation. The upper limit to the local mass density in the galactic disk, implied by the velocities of stars perpendicular to it, is the "Oort limit."

Radio-astronomy, spiral structure, and the galactic center. Following up on the discovery of cosmic emission at radio wavelengths by **Karl Jansky** and **Grote Reber**, Oort was the first to realize its far-reaching implications for astronomy. Of two fields of application, the measurement of the continuum spectrum and that of emission lines, he pursued in particular the latter after van de Hulst's prediction, in 1943, of the 21-cm emission line due to neutral interstellar hydrogen, HI. Its measurement became the primary objective, first of the Dwingeloo Radio Observatory (operational in 1956) and, next, of the Westerbork Synthesis Radio Telescope (in 1970) in the Netherlands, both largely the result of Oort's efforts. The measurement resulted in the mapping of the spiral-like distribution of HI in the Galaxy and of the HI structural patterns in other nearby galaxies. Oort's discovery, with C. A. Muller and Ernst Raimond, of clouds of neutral hydrogen gas apparently falling at high speed into the Milky Way from its halo or from inter-galactic space, was an important product of this program. Another topic of particular interest in Oort's research was the central region of the Galaxy with its explosive nature and small-scale spiral structure. He spoke in favor of a central black hole at least from the 1980s.

The Oort and Walraven map of polarization of the light of the Crab Nebula was probably the last serious optical astronomy done from the Netherlands, as the community turned to radio astronomy and to optical observatories in more favorable locations. It laid the ground for later studies by **Jan Woltjer** and others demonstrating the need for an ongoing energy source in the supernova remnant, later found in the form of a pulsar.

Large-scale structure in the distribution of galaxies. Whereas already early in his career Oort on several occasions had expressed his deep interest in the large-scale structures on a cosmological scale, he addressed these thoroughly only in the later stages of his career. His substantial review article on superclusters published in 1983 became the standard reference for many subsequent investigations.

Comets. Oort's interest in the origins of comets arose because a student, A. J. J. van Woerkum, had begun a thesis on the topic with Woltjer and became Oort's student after his first advisor's death. Oort postulated the existence of a spherical reservoir of comets beyond the domain of the major planets, now called the Oort cloud. Some comets will occasionally be perturbed in their orbit by passing stars; as a result comets may now be classified as either "new" ones that for the first time pass through the region of the Earth's orbit or "old" (periodic) ones that as a consequence of Jupiter's gravitation remain captured in the inner regions.

European Southern Observatory. Following up on a suggestion by **Walter Baade** of Mount Wilson Observatory, Oort in 1954 called a meeting of leading European astronomers and proposed that they join financial and personnel resources for the establishment of a joint southern observatory, a proposal he pursued with utmost perseverance. After a long struggle, requiring much diplomacy and insistence on the part of Oort, **André–Louis Danjon**, **Otto Heckmann**, and **Bertil Lindblad**, the international convention was signed in 1962.

International Astronomical Union [IAU]. A strong advocate of international collaboration, Oort contributed considerably to the activities of the IAU. From 1935 until 1948 he was its general secretary, except during the years 1940–1945 (World War II) during which the secretariat was filled temporarily by **Walter Adams** of Mount Wilson Observatory. Oort's efforts contributed considerably to the resumption of cooperation within the IAU among astronomers from the formerly hostile countries. During the years 1958–1961 Oort was president of the IAU. At the time of the General Assembly [GA] of the International Union in 1976 at Grenoble, France, Oort was the only remaining member to have attended all of the GAs since the first in Rome in 1922.

Adriaan Blaauw

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Öpik, Ernst Julius

Born **Port Kundu, (Estonia), 23 October 1893**
Died **Bangor, Co. Down, Northern Ireland, 10 September 1985**

Ernst Öpik was among the first to put forward a number of ideas now regarded as part of mainstream astronomy, including a way of measuring distances to other galaxies (before it was generally agreed that there were other galaxies), a composition discontinuity as the cause of red-giant structure, and the need for a three-body process to carry nuclear reactions beyond the formation of helium to carbon and heavier elements.

Öpik was educated at Tallinn High School in Estonia and graduated with honors and a gold medal in 1911. At school, and later at university, he supported himself and helped his parents by teaching mathematics, science, and languages. He had to choose between music and science and decided on a career in astronomy.

Öpik graduated with first class honors from Moscow Imperial University in 1916 and held teaching posts there for 3 years. During the Bolshevik Revolution he volunteered for the White Russian Army. From 1919 to 1921 he headed a new astronomy department at the Turkestan University in Tashkent and then returned to his native Estonia as associate professor at Tartu University, where he obtained his doctorate in 1932 with a thesis on meteor observations.

Between 1930 and 1934 Öpik held the post of research associate and visiting lecturer at Harvard University and Harvard College Observatory. During this time he founded the meteor research group at Harvard. He then returned to Estonia and established his family home there.

After the German occupation of Estonia in 1941, and with the Soviet armies about to reoccupy the country in 1944, Öpik and his family fled to the west by horse and cart. They eventually reached Hamburg Observatory where they were given succor. Öpik became professor of astronomy in the Baltic University in Hamburg, which was set up to accommodate displaced scholars and students from the east. When his plight became known, **Eric Lindsay**, a Harvard graduate and director of Armagh Observatory from 1937, invited Öpik to Armagh, Northern Ireland, in 1947 as a research associate. He remained at Armagh until his retirement in 1981.

While he was still an undergraduate at Moscow University in 1916, Öpik wrote a paper on the densities of 40 visual binaries, which he derived from their corrected surface brightness. He excluded from his survey one binary with known orbital elements, o_2 Eridani (40 Eri B). Taking its spectrum as A0, its parallax as 0.17 arc seconds, and the mass ratio as unity, he found a density 25,000 times that of the Sun. Assuming that this was an impossible result, Öpik sought another explanation. He was not the first to think the density of a white dwarf was incredible; in 1905, **John Gore** of Dublin estimated the density of Sirius B at nearly 32,000 times the Sun's and thought it "entirely out of the question."

In 1921 Öpik published an article in the Russian astronomy magazine *Mirovedenie* that included an estimate of the distance to the Andromeda Nebula from dynamical considerations. By connecting the observed velocity of rotation of the Nebula to the centripetal acceleration, and hence its gravitational attraction and mass, he obtained a distance of 785 kpc. The following year a similar paper appeared in the *Astrophysical Journal* and, assuming a new value for the mass–luminosity ratio, his estimate was now 450 kpc. These values compare well with a modern estimate of 690 kpc considering that they predate the extragalactic scale based on Cepheid luminosities.

In 1932 Öpik set out to investigate the stability of a large cloud of meteors and comets attached gravitationally to the Solar System. He calculated the perturbation effects of stars passing through the cloud, making the reasonable assumption that objects in very large orbits about the Sun would spend most of their time at aphelion. He decided that a system of comets could persist without great losses for over 3 billion years, in orbits about the Sun, at distances up to 5 parsecs. Subsequent studies have reduced this distance by a large factor, but the basic conclusion is still valid. **Jan Oort** introduced his concept of a cloud of comets surrounding the Sun in 1950.

In 1938 Öpik tackled the problem of the origin of red giant stars, which must have sizes up to hundreds of times that of the Sun, because they are very bright, although very cool. He realized that in stars like the Sun, nuclear burning takes place only in the central 10% by mass. As the available hydrogen fuel is depleted, there is no longer enough pressure to support the central regions; the core collapses; and, as a result, the outer envelope expands to an enormous size. Öpik's hand calculations were confirmed about 10 years later by **Fred Hoyle** and **Martin Schwarzschild** using electronic calculators.

In 1950 Öpik put forward a theory to explain the occurrence of ice ages on the Earth with periods of several hundreds of millions of years. He suggested that transport of fresh hydrogen into the solar core could increase the rate of energy generation, affecting temperatures on the Earth. Other factors are now thought to be more important.

Öpik made many contributions to knowledge of the planets and the minor bodies of the Solar System. He anticipated the desert-like nature of the surface of Venus, and his prediction of craters on Mars was confirmed 15 years later by planetary probes. His statistical studies of Earth-crossing comets and asteroids led to a better understanding of the dynamics of these bodies and their influence on the Earth. In recognition of this work, Minor planet (2099) was named for Öpik.

In 1950, on the initiative of Lindsay and with the active support of **Hermann Brück**, the *Irish Astronomical Journal* began publication with Öpik as editor. Over the following three decades the journal became a channel for his views on astronomical and other matters. During this time he was also a visiting professor in the Department of Physics and Astronomy at the University of Maryland.

Öpik was an accomplished amateur musician, both as a performer and composer. He wrote some 3,000 pieces for piano as well as some choral works. An appraisal of his musical attainments is given by Mary de Vermond of the University of Maryland in a special issue (1972) of the *Irish Astronomical Journal*.

For his contributions to astronomy, Öpik received many honors. He was fellow of the Estonian Academy of Sciences from 1938, member of the Royal Irish Academy from 1954, foreign associate of the United States National Academy of Sciences [NAS] from 1975, and foreign honorary member of the American Academy of Arts and Sciences from 1977. He received honorary degrees of Doctor of Science from Queen's University, Belfast, in 1968 and from the University of Sheffield in 1977. He received the J. Lawrence Smith Medal of the NAS in 1960, the F. C. Leonard Medal of the International Meteoritical Society in 1968, one of six Gold Medals of the American Association for the Advancement of Science in 1974 awarded in connection with the fourth centenary of **Johannes Kepler**'s birth, the Gold Medal of the Royal Astronomical Society in 1975, the Catherine Wolfe Bruce Gold Medal of the Astronomical Society of the Pacific in 1976, and the *Grand Prix* of the Louis Jacot Foundation "La Pensee Universelle" in 1978. He was elected a fellow of the Royal Astronomical Society in 1949.

On his retirement at the age of 88, Öpik went to live in the seaside town of Bangor. He continued as an associate editor of the journal until his death. He was survived by his second wife Alide, and by one son and five daughters. Öpik's grandson, Lembit Öpik, has served as a Member of Parliament at Westminster in London.

Ian Elliott

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Oppenheimer, J. Robert

Born **New York City, New York, USA, 22 April 1904**

Died **Princeton, New Jersey, USA, 18 February 1967**

American physicist J. Robert Oppenheimer features in world history as the leader of the Manhattan Project, which developed the first American atomic (fission) bombs, but his contributions to astronomy concern the structure of neutron stars (using the eponymous Tolman–Oppenheimer–Volkoff equation of state) and the unstoppable collapse of objects larger than some critical mass.

Oppenheimer was the elder of two sons. (The younger, Frank Oppenheimer, was also a physicist.) Robert graduated from the Ethical Culture High School in New York at age 16. He received his A.B. in physics from Harvard University in 1925 (which also awarded him an honorary D.Sc. in 1947, one of many honorary degrees) and his Ph.D. in physics in 1927 from Göttingen University in Germany for work with Max Born on what is now called the Born–Oppenheimer approximation (for quantum mechanical calculations of systems of particles with very different masses; they worked on molecules). After brief fellowships in Leiden and Zürich (1928/1929), he took up joint appointments at the California Institute of Technology and the University of California, Berkeley, progressing from assistant professor (1929–1931) to associate (1931–1936) to full professor (1936–1947).

Oppenheimer apparently had a gift for languages, and after his brief stays in Göttingen and Leiden was able to write scientific papers and converse in German and Dutch. His adult nickname, Oppie, was an Americanization of the Dutch. Oppenheimer married Katharine Harrison in 1940. Neither of their children, Peter and Katharine, evinced any interest in science.

Oppenheimer was director of the Los Alamos National Laboratory from 1943 to 1945 and professor of physics and director of the Institute for Advanced Study in Princeton from 1947 to 1966. He served as chair of the General Advisory Committee of the Atomic Energy Commission from 1946 to 1952, was president of the American Physical Society (1948), and was elected to a number of national academies of science (United States, Danish, Brazilian, and most remarkably, the Japanese).

It can be argued that his most important long-term influence on physics was in building up the large theory groups at Caltech and Berkeley, so that an American no longer had to go to Europe, as Oppenheimer had, for advanced training. Among his students who have become important astrophysicists are **Philip Morrison** and Robert Christy (professor emeritus, Caltech). The best known of his post-doctoral fellows in the area of astrophysics and gravitation was probably Leonard Schiff, who developed the theory of one of the classic astronomical tests of general relativity.

Oppenheimer's work on topics relevant to astrophysics was confined to a narrow time window, beginning with a 1937 attempt, with Robert Serber, to identify a particle newly discovered in the cosmic rays (now called the μ meson or muon) with a particle predicted by Hideki Yukawa to carry the strong or nuclear force. The Yukawa particle, now called the pion, was later discovered in the cosmic rays and, although its mass is similar to that of the muon, it is otherwise fundamentally different.

Two papers, with Serber and with **George Volkoff**, in 1937–1938 contained the first careful calculations of the structure of neutron stars, which had been predicted in 1933/1934 by **Walter Baade** and **Fritz Zwicky**. They showed in particular that there was an upper limit to the mass of a stable neutron star, similar to the Chandrasekhar limit for white dwarfs. The number they found, 70% of the mass of the Sun, was too small because they had not been able to include the effect of the nuclear force, but only those of quantum mechanics and general relativity. A 1939 paper with **Hartland Snyder** was entitled "On Continued Gravitational Contraction," and dealt with the behavior of a mass above the critical limit. It is generally considered to be a prediction of black holes. Oppenheimer did not live to see observational confirmation of either neutron stars (the 1967/1968 discovery of pulsars) or black holes (the 1972 measurement of the mass of the compact object in the X-ray binary Cygnus X-1).

In the postwar period, Oppenheimer did very little original scientific research, but did make some contributions on the role of mesons in generating cosmic-ray showers. He mentored a number of younger physicists in this period, including Tsung-Dao Lee and Chen Ning Yang, who shared the 1957 Nobel Prize in Physics for the prediction of parity nonconservation.

The last 25 years of Oppenheimer's life were inevitably dominated by the development of the atomic bomb (regrets for which he expressed the form of saying that "physicists had known sin") and its aftermath. His period of influence in the United States government and postwar development of atomic weaponry and energy ended abruptly when his security clearance was withdrawn in 1953. The subsequent trial divided the American physics community, including especially those who had worked with him closely at Los Alamos. He was given the Fermi Award in 1963 by the Atomic Energy Commission in a not uncontroversial partial apology.

President Kennedy had been scheduled to present the Fermi award on 2 December 1963. As it turned out, the presentation was made by President Lyndon B. Johnson, with the words:

> Dr. Oppenheimer, I am pleased that you are here today to receive formal recognition for your many contributions to theoretical physics and to the advancement of science in our nation. Your leadership in the development of an outstanding school of theoretical physics in the United States and your contributions to our basic knowledge make your achievements unique in the scientific world.

Oppenheimer's response typified the courtly grace, or pomposity, that had made him either loved or hated by so many:

> I think it is just possible, Mr. President, that it has taken some charity and some courage for you to make this award today. That would seem to me a good augury for all our futures . . . These words I wrote down almost a fortnight ago [that is, before Kennedy's death]. In a somber time, I gratefully and gladly speak them to you.

He developed throat cancer soon after, perhaps as a result of inveterate pipe-smoking and perhaps also from the effects of radiation exposure during the Los Alamos years, and died very shortly after being filmed in a tribute to Enrico Fermi.

Virginia Trimble

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Oppolzer, Egon Ritter von

Born **Vienna, (Austria), 1869**
Died **Vienna, (Austria), 15 June 1907**

Egon Oppolzer was the son of **Theodor von Oppolzer**. He was educated at the University of Vienna and the University of Munich; in 1897 he became an assistant at the Prague Observatory, where he discovered the variability of the minor planet (433) Eros. Oppolzer was appointed a professor of astronomy at the University of Innsbruck in 1901.

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Oppolzer, Theodor Ritter von

Born **Prague, (Czech Republic), 26 October 1841**
Died **Vienna, (Austria), 26 December 1886**

Though trained as a physician, Theodor von Oppolzer excelled at celestial mechanics and published a monumental volume on the elements of all solar and lunar eclipses, visible from 1207 BCE to 2163. Oppolzer's father, Johann von Oppolzer, was a well-known physician, specialist on internal diseases, and professor of medicine at the Universities of Prague, Leipzig, and Vienna. Oppolzer received a private education (1851–1859) before he entered the Piaristen-Gymnasium in Vienna, from which he graduated *summa cum laude*. While his teachers encouraged his abilities in mathematics and science, Oppolzer fulfilled his father's wish that he study medicine at the University of Vienna, where he received his medical degree in 1865. Yet, it seems that he never wanted to work as a physician. In 1865, Oppolzer married Coelestine Mauthner von Markhof; the couple had six children. One of his sons, **Egon von Oppolzer**, became professor of astronomy at the University of Innsbruck.

Oppolzer's intellectual talents enabled him to pursue mathematical astronomy even through the course of his medical studies. His parents supported his interests by financing a private observatory located on the outskirts of Vienna, which was christened "Sternwarte Wien-Josefstadt." This observatory was equipped with a 7-in. refracting telescope, a meridian circle, and a wide-field cometseeker. Before the new Vienna Observatory was erected in the late 1870s, Oppolzer's principal telescope was likely unsurpassed in the Austro–Hungarian monarchy.

Two of the principal influences on Oppolzer's astronomical interests were **Maurice Löwy** and **Edmund Weiss**, both of whom then worked at the original Vienna Observatory. Loewy and Weiss observed minor planets and comets and computed their orbital elements and ephemerides. Oppolzer's first publication concerned the orbit of comet C/1861 G1. By the time his medical studies were completed, he had published some 56 papers in astronomical journals, dealing chiefly with orbit determinations. The following year, Oppolzer became a *Privatdozent* (lecturer) at the University of Vienna, without having acquired a Ph.D.

Oppolzer's preliminary research dealt with the orbital determinations and ephemeris calculations of asteroids and comets. Yet, he soon found ways to improve upon the cumbersome methods and auxiliary tables used at that time. These techniques enabled Oppolzer to recover the lost minor planets (62) Erato, (73) Klytia, and (91) Aegina. In 1870, he published the first volume of a textbook on orbit determination, whose methods for computing an elliptical orbit from three or four positions converged toward a solution much more rapidly than the method of **Carl Gauss**. In that same year, Oppolzer was appointed an extraordinary professor of astronomy and advanced geodesy at the University of Vienna.

Oppolzer undertook a major scientific and administrative task in the supervision of his nation's geodetic studies, which included a series of longitude measurements between Austrian cities and other European capitals. Reflecting certain patriotic motivations, this large-scale undertaking also evinced international cooperation in science on an unprecedented scale. Its ambitious goals were to conduct a topographic survey and establish the precise shape of the Earth. In 1873, Oppolzer became director of the Austrian Gradmessungs-Bureau (Geodetic Survey); in the following year, he was appointed Austrian representative to the International European Geodetic Congress (and later became its vice president). Between 1873 and 1876, Oppolzer personally supervised some 40 longitude determinations. Apart from his role as manager, he contributed ideas for new instruments that were applied in other countries.

In connection with the problem of the Earth's figure, Oppolzer was interested in gravity determinations. He improved existing methods of measurement by the use of reversible pendulums and eliminated sources of error. In 1883, the first determination of the absolute intensity of gravity was made in the basement of the new Vienna Observatory. Some years before its adoption in 1875, Oppolzer had promoted establishment of the metric system in the Austro–Hungarian monarchy. For these scientific and administrative activities, he was decorated with a series of medals from various countries and elected a member of numerous scientific institutions and academies. Oppolzer was awarded an honorary doctorate from the University of Leiden in 1871.

In spite of these responsibilities, Oppolzer never gave up astronomy. He was engaged with preparations for an expedition to Jassy in Romania to observe the 1874 transit of Venus. In 1875, Oppolzer had been offered the directorship of the Gotha Observatory but declined the invitation. In that same year, he was made an ordinary professor; by 1879, he had been elevated to the rank of full professor at the University of Vienna. Those years also witnessed construction of the new Vienna Observatory. After its director, **Karl von Littrow**, was released from teaching, the bulk of that activity fell to Oppolzer and Weiss. The former also prepared the second volume of his textbook on orbit determination, involving perturbation theory, which appeared in 1880.

Oppolzer's studies in celestial mechanics culminated with his refinements to the theory of the Moon's motion and the Sun–Earth–Moon system in connection with solar and lunar eclipses. Oppolzer possibly became interested in this subject on the occasion of the total solar eclipse of 18 August 1868. As a participant in the Austrian expedition to Aden, he was responsible for determining the position of the observing station and the times of contacts during the eclipse.

To arrive at a more accurate determination of the Moon's orbit, it was necessary for Oppolzer to compare historical and contemporary eclipse observations by means of a uniform theory. He began his investigations with the best available lunar theory of **Peter Hansen**. Yet, even here he found irregularities that could not be explained by the theory. Oppolzer then modified Hansen's theory and developed appropriate tables that allowed more efficient calculations to be made. In 1881, he published his "Syzygien-Tafeln für den Mond" (Syzygy tables for the Moon), which enabled the times of new and full Moons to be calculated in the distant past or future.

Oppolzer's study of eclipses reached its climax with the 1885 publication of his monumental *Canon der Finsternisse* (Canon of Eclipses). This massive undertaking required the assistance of ten human computers, half of whom worked as volunteers, half of whom were paid privately by Oppolzer. The calculations were performed by two independent groups and their results compared for accuracy. Described in 1887 as "one of the greatest works of calculation which has ever been accomplished by man," the *Canon* contains the elements for approximately 8,000 solar and 5,200 lunar eclipses, including visibility tracks of the solar eclipses. When completed, the *Canon* was of special use for chronological research, offering precise dates of historical events that otherwise might be known only to the nearest century.

Appearing well before the advent of mechanical or digital calculations, Oppolzer's *Canon* was reprinted (and translated into English) as late as 1962. In turn, his work has stimulated the computation of other eclipse catalogs, some more extended and specialized than the original. A newer compilation (1983), based on the more refined lunar theory of **Ernest Brown**, and generated by a digital computer, provides a significant test of the accuracy of Oppolzer's *Canon*.

Oppolzer did not live long enough to finish his modified lunar theory; his widow financed the partial completion of his manuscript by enlisting those computers who had worked on the *Canon der Finsternisse*.

A crater on the Moon and several minor planets are named for the subject or his relatives: (1492) Oppolzer, (237) Coelestina (his wife), (228) Agathe (his youngest daughter), and (153) Hilda (a daughter who died as a child).

Anneliese Schnell

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Oresme, Nicole

Born **diocese of Bayeux, (Calvados), France, *circa* 1320**
Died **Lisieux, (Calvados), France, 11 July 1382**

French bishop, scholastic philosopher, economist, and mathematician Nicole Oresme is considered today as one of the principal forerunners of modern science. Oresme's contributions in mathematics and physics are considered decisive ideas for the development of modern science in the 16th and 17th centuries. Editions of Oresme's work were published well into the Renaissance.

Probably Oresme took his philosophical training at the University of Paris under **John Buridan**, whose influence in Oresme's works is evident. By 1348 he had a scholarship in theology at the college of Navarre at Paris, of which he became grand master (head) in 1356. Oresme left Navarre after his appointment as a canon at Rouen (1362). Later he was appointed Canon at the Sainte-Chapelle in Paris (1363) and Dean of the Cathedral of Rouen (1364). At the behest of King Charles V of France, from about 1370 Oresme translated and annotated many works of **Aristotle**, including *On the Heavens*, from Latin into French. In his commentaries he expressed his critique of several Aristotelian tenets by developing many original astronomical, physical, and economic ideas. As a reward for this extended and difficult work, Charles V had him appointed Bishop of Lisieux in 1377. Little is known of Oresme's last years.

Oresme is the author of more than 30 works, the majority of which are still unpublished and remain in manuscript form. As a scholastic philosopher he is famous for his critique of several Aristotelian positions. Oresme rejected two of Aristotle's main definitions, replacing them with his own – he rejected the definition of the place of a body as the inner boundary of the surrounding medium in favor of a definition of place as the space occupied by the body, and he replaced the definition of time as the measure of motion with a definition of time as the successive duration of things, independent of motion.

Oresme's main contributions to astronomy, mathematics, and kinematics are contained in several works produced throughout his life. His two major scientific works are the *Tractatus de configurationibus qualitatum et motum* (Treatise on configurations of qualities and motions), and the *De proportionibus proportionum* (On ratios of ratios). Oresme's main astronomical views are exposed in his early works *Questiones de Celo* and *Questiones de Spera*, in a work opposing astrology, *Questio contra divinatores*, and in his later work written in French, *Le livre du ciel et du monde* (Book on the heavens and the world), a translation of and commentary on Aristotle's *On the Heavens*.

A very interesting characteristic of his argumentation is that it often permitted Oresme to suggest unorthodox and radical philosophical ideas while disclaiming any commitment to them. For example, in treating the question of the plurality of worlds, he stressed the possibility that God by His omnipotence could create such a plurality, though he finally rejected this in favor of a single Aristotelian cosmos. Another famous example of Oresme's argumentation is his study of the rotation of the Earth. He brilliantly argued against the "proofs" of Aristotle for a stationary Earth, mainly in his *Le livre du ciel et du monde*. With a series of arguments based mainly on the idea of the complete relativity in the detection of motion and the demonstration that all observed phenomena can be saved equally well by the diurnal rotation of the Earth as by the rotation of the heavens, Oresme explained why we cannot exclude the possibility of a rotating Earth. Though he finally concluded, "The truth is, that the earth is not so moved but rather the heavens," he added, "However I say the conclusion [about the nonexistence of a such rotation] cannot be demonstrated but only argued by persuasion."

Another original astronomical idea of Oresme is the metaphor of the heavens as a mechanical clock, which is considered the first attempt to understand mechanically the celestial motions. He suggested the possibility that God implanted in the heavens at the time of their creation special forces and resistances – differing from those on Earth – by which the heavens move continually like a mechanical clock. Through his opposition to astrology Oresme was also able to expose other aspects of his views about the relation of celestial and terrestrial phenomena. For Oresme terrestrial phenomena arise from natural and immediate causes rather than from celestial influences, with the exception of the influences of the light of the Sun. Only ignorance, he claimed, causes men to attribute terrestrial phenomena to the heavens, to God, or to demons. Oresme composed his anti-astrology dissertation in Latin, but so strong was his desire to divert people from the false science that he produced a short tract against the practice in French.

Finally we must mention Oresme's idea to develop mathematical arguments in order to prove the probable incommensurability of the ratio of any two celestial motions. He started from a suggestion of the theologian–mathematician **Thomas Bradwardine** that an arithmetic increase in velocity corresponds to a geometric increase in the original ratio of force to resistance. Oresme went on to give an extraordinary elaboration of the problem of relating ratios exponentially by a treatment of fractional exponents conceived as ratios of ratios. His idea was the distinction between irrational ratios of which the fractional exponents are rational and those of which the exponents are themselves irrational. Based on this treatment he claimed (without any real proof) that the ratio of any two celestial motions is probably incommensurable. This excluded precise predictions of successively repeating conjunctions, oppositions, and other astronomical aspects with the methodology of astrologers. Oresme presented his original method for manipulating ratios in an independent work, the *Algorism of Ratios*.

Dimitris Dialetis

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Oriani, Barnaba

Born **Garegnano near Milan, (Italy), 17 July 1752**
Died **Milan, (Italy), 12 November 1832**

Barnaba Oriani was an accomplished observer and observatory director who contributed to planetary astronomy. He was of humble origins. His father Giorgio worked as a mason; his mother was Margherita Galli. Oriani began his studies in the Certosa of Garegnano, then at the College of San Alessandro, Milan, where he was educated and supported by the Barnabites (a religious order of the Catholic Church). He later joined the Barnabites, and, after studying the humanities, physical and mathematical sciences, philosophy, and theology, was ordained as a priest at the age of 23 in 1776. Despite his youth, he was admitted to the competition for teaching mathematics at the Como Gymnasium. His rejection diverted him to pursue his love of astronomy; shortly after his ordination Oriani was appointed to the staff of the Observatory of Brera in Milan. He became assistant astronomer in 1778.

For 5 months in 1786 Oriani traveled to Brussels, Amsterdam, and London, where he met a host of scientific luminaries. In 1787 Oriani was offered the full professorship of astronomy and directorship of the observatory to be founded in Palermo. He excused himself as he was not willing to leave his observatory in Brera. In any event, it was **Giuseppe Piazzi** who became the director of Palermo. These two met only once, in Brera in 1789, when Piazzi was returning from England and France. Piazzi had in Oriani a sincere and loyal friend; their correspondence spanning several decades became ever more frank as the years went on.

When observing the comet of 1779 (C/1799 A1), which had been discovered by **Johann Bode** on 6 January and independently by **Charles Messier** on 18 January, Oriani observed three "nebulous stars," namely M49, M60, and M61. M49 had been discovered in 1771 by Messier. Oriani found M49 on 22 April. (Messier had discovered it in 1771.) M60 had been discovered first by **Johann Köhler** on 11 April, then by Oriani the next day and by Messier on 15 April. M61, however, was the original discovery of Oriani on 5 May 1779, and was seen by Messier 6 days later.

Oriani's greatest work involved the orbit calculation of Uranus after its discovery by **William Herschel** in March 1781. After **Jean Bochart de Saron**, **Anders Lexell**, and others had shown that Uranus was not on a parabolic orbit and had obtained an approximate circular orbit, Oriani calculated the planet's elliptical orbit in 1783. He improved this calculation in 1789 by taking into account the perturbations of Jupiter and Saturn.

In 1786 Oriani conducted trigonometrical operations for measuring an arc of the meridian over Lombardy. He continued the ephemeris begun by **Joseph Lagrange**, and inserted in it many able and valuable discussions on the lunar theory, on refraction, and various practical and theoretical matters. His skill in spherical trigonometry enabled him to be the first in computing the path and perturbations of the first minor planet, (1) Ceres (discovered by his friend Piazzi in 1801). Oriani became one of the leading observers of the first four asteroids.

In 1802 Oriani was made director of the Observatory of Brera, and he became one of the founding members of the National Institute of the Italian Republic. That year he was sent to Bologna by order of the Italian Republic and found "astronomy almost abandoned." Oriani tried to revive the observatory there by offering its directorship to Piazzi, but he refused.

Oriani was long known in scientific circles as abbot and professor. When Napoleon established the republic in Lombardy, Oriani refused absolutely to swear hatred toward monarchy; the new government modified the oath of allegiance in his regard, retained him in his position at the observatory, and made him president of the commission appointed to regulate the new system of weights and measures. When the republic was transformed into the Napoleonic kingdom, Oriani received the decorations of the Iron Crown and of the Legion of Honor, was made count and senator of the kingdom, and was appointed (in company with Angelo de Cesaris) to measure the arc of the meridian between the zeniths of Rimini and Rome.

In private life Oriani was of a pleasing and amiable disposition, and a great encourager of study amongst the youths of his acquaintance. A longtime acquaintance, **Giovanni Plana** of Turin, wrote of him in tribute: "His splendid talents, by which he has rendered illustrious not only the Observatory of Milan, but the whole of Italy, made him highly respected, and caused his loss to be seriously deplored."

Clifford J. Cunningham

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Orontius Finaeus

➔ **Finé, Oronce**

Osiander, Andreas

Born **Gunzenhausen, (Bavaria, Germany), 19 December 1498**
Died **Königsberg (Kaliningrad, Russia), 17 October 1552**

German theologian, reformer, astronomer, and mathematician Andreas Osiander's most notorious role in astronomy was the writing of an anonymous preface to the first edition of **Nicolaus Copernicus**'s *De Revolutionibus Orbium Coelestium*, suggesting that the heliocentric idea was merely a mathematical hypothesis and not the actual way the Solar System was laid out.

Osiander was admitted to the University of Ingolstadt on 9 July 1515, but left without a degree. He was ordained a priest in Nuremberg in 1520. In 1522 Osiander joined the cause of the Reformation, and became one of the leading spokesmen of Lutheranism. He frequently participated as a representative of Nuremberg's clergy at gatherings of Lutherans, among others the Marburg Conference (1529), the Diet of Augsburg (1530), and the signing of the Schmalkaldic Articles (1537). In 1548 Osiander refused to agree to the pro-Catholic Augsburg Interim, the compromise temporary settlement of the religious wars. His refusal made it necessary for him to leave Nuremberg, and he went to Königsberg. In 1549 Duke Albrecht of Prussia, who regarded Osiander as his spiritual father, appointed him as pastor of one of Königsberg's churches and professor of theology at the newly founded university of the city. Osiander retained the support of the duke until his sudden death.

Osiander was a rigid man, given to strong opinions that he did not express with moderation. His style fomented theological divisions in Königsberg that subsequently involved the whole German Evangelical Church. As a theologian Osiander developed a mystical interpretation of the Lutheran doctrine of justification by faith. His views found supporters among the strict Lutherans, who refused any compromise with Rome or Calvinism, and were opposed by the moderate wing, headed by Philip Melanchthon and the group of Wittenberg University, who strove for reconciliation.

Though Osiander was primarily engaged in theological matters, he also entertained a deep interest in mathematics and astronomy. It is known that Osiander corresponded with the mathematician **Girolamo Cardano** about horoscopes for some 5 years. But his place in the history of astronomy is mainly due to his involvement in the first edition of Copernicus's *De revolutionibus orbium coelestium*, and the famous preface that he inserted, in which he warned readers that the book was not intended to propose more than a mathematical hypothesis. Osiander was approached for the publication of the book by **Rheticus** professor at the University of Wittenberg and an admirer of Copernicus. Osiander is said to have been shocked by the implications of Rheticus's *Narratio prima*, the first published account of the Copernican system. He never accepted the possibility that the proposed system could be anything more than another attempt to "save the phenomena."

On 20 April 1541, in letters to Rheticus and Copernicus, Osiander stated his opinion, while Rheticus was waiting in Frombork (Frauenburg) for Copernicus to put the final touches on the manuscript of *De revolutionibus*. Osiander urged the inclusion in the introduction of the statement that even if the Copernican system provided a basis for better and easier astronomical computations, it might still be false. Historians agree that Copernicus firmly rejected Osiander's recommendation. At the time of the printing of the book, Copernicus was taken seriously ill in Frombork, and Rheticus supervised the printing of the manuscript in the printing shop of Johannes Petreius in Nuremberg. In the final phase of the printing Rheticus was appointed professor of mathematics in the University of Leipzig and was obliged to go there; he left Osiander to see through the final stages of the publication. Osiander surreptitiously slipped in an unsigned preface, denying that the book intended to propose more than a mathematical hypothesis, and represented as impossible a task of discovering how the Universe is laid out.

Osiander's statement was a reassertion of the traditional position regarding the astronomical method known as "save the phenomena." Copernicus appears to have believed in the reality of his system, but because Osiander's preface was unsigned, it was widely believed to represent the views of Copernicus. For this reason it was thought by most in succeeding years that Copernicus himself had not really believed that the Earth could move.

When copies of *De revolutionibus* reached Rheticus in Leipzig, he became enraged and sent to the City Council of Nuremberg a sharp protest written by Tiedemann Giese, one of the closest friends of the deceased Copernicus. Petreius replied that he had received the preface in a form undifferentiated from the rest of the material. Whereas Osiander never publicly acknowledged his authorship of the interpolated preface, he did so privately, and finally in 1609 in *Astronomia nova* **Johannes Kepler** stressed that Osiander, not Copernicus, had penned this preface.

Dimitris Dialetis

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Outhier, Réginald [Réginaud]

Born **La Marre, (Jura), France, 16 August 1694**
Died **Bayeux, (Calvados), France, 12 April 1774**

Réginald Outhier was an observational astronomer who also undertook geodetic work in Lapland and France. He studied in Poligny, Dole, and Besançon, the new capital of Franche-Comté. Outhier became a priest of the diocese of Besançon, acting as vicar at Montain near Lons-le-Saunier. It is there that he first became interested in astronomy.

In 1726 Outhier invented a moving globe that showed the apparent movement of the Sun and the Moon, and the movement of the nodes of Moon's orbit. This globe, 5 in. of diameter, was executed by J. B. Catin; it is represented in the *Machines de l'Académie* and was praised by A. Thiout in his treatise on watches and clocks (1741). As a consequence of his work, Outhier was named on 1 December 1731 a correspondent of **Jacques Cassini** (then in 1756 of **César Cassini de Thury**) at the Academy of Sciences in Paris, where he was invited to present his globe.

Paul d'Albert de Luynes, Bishop of Bayeux since 1729, who occupied his leisure in astronomy, gnomonics, and meteorology, invited Outhier to come to Bayeux to act as his secretary. Upon his arrival, Outhier sketched in the bishop's library a large meridian with lines marking the time from 5 min before and after real noon.

In 1733, Outhier joined the team of Cassini II, which measured the perpendicular to the Paris meridian; he participated in the work from Caen to Saint-Malo and (the last measures) in Bayeux. Then Outhier drew a map of the diocese of Bayeux (published in 1736). On the basis of these works, the Academy of Sciences designated him, in 1735, a member of the Lapland expedition commanded by **Pierre de Maupertuis**. It also provided him with a pension of 1,200 livres.

Outhier left Bayeux in December 1735 and, after 5 months of preparation, the Lapland expedition members proceeded to Dunkerque, where the Swedish physicist, **Anders Celsius** (coming from London with some instruments) met them. They took a ship on 2 May 1736, arriving in Tornea, near the Arctic Circle, on 22 June. Outhier wrote the "Journal du Voyage" in which he described the measures of the arc of the meridian done from 1736 till 1737 and the measure of a baseline on the ice in winter. He also drew several maps of the areas covered. This work, published in 1744, described the charming simplicity of life in Sweden and the habits of the Laplanders. It was translated into English in 1777.

Back in Bayeux, Outhier continued his geodetic work for the *Carte de France* at the request of Cassini III. In 1735 and 1736, the Paris Observatory triangulated the coasts of Picardy and Brittany and, in 1737, César Cassini de Thury and **Giovani Maraldi** followed the coast southward, leaving Abbé Outhier in charge of finishing the remaining Norman coasts near Cherbourg.

From 1749 until 1755, Outhier drew up the diocese almanacs. In 1750, he reported a light earthquake felt from Avranche to Cherbourg. He published in 1755 a map of stars of the Pleiades, the 35 main stars of which had been observed by **Pierre–Charles Le Monnier** and the others by himself. At Bayeux, Outhier made meteorological and astronomical observations: for example, the transit of Venus of 6 June 1761 with a 36-in. focal length refractor with a micrometer, and the lunar eclipse of 8 May 1762. He also traveled to Sens and drew topographical maps of the Meaux and Sens dioceses, probably called there by Monsignore de Luynes.

Outhier was named in 1748 Canon of the Bayeux cathedral, a benefice he left in 1767 to concentrate upon his scientific work. He had participated in two of the most important scientific operations of 18th-century France, the *Carte de France* and the Lapland expedition. Outhier was a correspondent of the Paris Academy of Sciences; he was also member of the Berlin Academy, and in France of the Caen and Besançon academies.

Simone Dumont

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Ovid

Born **Sulmona (Sulmona, Abruzzo, Italy), 20 March 43 BCE**
Died **Tomis (Constanza, Romania), 17**

In a number of his poems the Roman poet Publius Ovidius Naso describes celestial mythology, constellations, and calendrical lore related to the sky. The chief source for his life is one of his own poems, *Tristia* 4.10. Descended from an equestrian family, he was born in

Sulmo, a mountain town some 90 miles northeast of Rome. Ovid and his brother were sent to Rome at an early age for training in rhetoric and to prepare for careers in public life. After an extended tour of the Greek East, Ovid returned to Rome to hold a few minor public offices but chose rather to devote himself to poetry under the patronage of Marcus Valerius Messalla Corvinus (64 BCE –8). The poet soon became the darling of the brilliant social life of the capital.

In 8, Emperor Augustus, for reasons not fully known, exiled Ovid to Tomis, the modern Constanza, a barely Romanized outpost on the western coast of the Black Sea. Life there was a sad and harsh change from his former life at Rome. After years of unsuccessful appeals to Augustus and to his successor Tiberius, the poet died there. Ovid was married three times and had at least two children; his last wife remained behind in Rome during his exile. Ovid has greatly influenced subsequent western literature and art, particularly with his love poetry.

Although clearly informed by literary rather than scientific considerations, much astronomical material is found in three of Ovid's works. His *Aratea*, a Latin version of **Aratus**'s *Phaenomena*, is now lost except for two brief fragments. Two other major works incorporating celestial references do survive, however, and both seem to have been composed at about the same time, before and during the poet's exile: the *Fasti* and the *Metamorphoses.* Taken together, these two works complement one another in Ovid's incorporation of celestial storytelling.

The 15 books of the *Metamorphoses* retell in dactylic hexameters almost the whole range of classical mythology based on the idea of change. The tales are mostly Greek in origin, but the last three books are concerned with Roman myth and history right up to Ovid's own day. An Ovidian cosmogony begins the *Metamorphoses* (1.5–88). Reminiscent of the beginning of **Hesiod**'s *Theogony*, the account details the evolution of the Universe out of disorder (*chaos*) and the role of the four elements in the process. Ovid also ascribes to divine intervention the eventual creation of the world and the appearance of humans. In Book Two, the story of Phaethon, with his attempt to drive the chariot of the Sun, features engaging passages with astronomical themes, including a description of the palace of the Sun and the constellations that the reckless young man encounters in his uncontrolled ride through the heavens (2.1–327). Elsewhere, astral myth in the form of catasterism appears. The most prominent of such episodes is that of Callisto and Arcas (2.410–530), which is also retold at *Fasti* 2.153–192. The tale is exemplary for Ovid's literary methodology: As in a number of other tales of terrestrial beings transported to the heavens, the poet reworks Aratus's version. The *Metamorphoses* concludes with the poet's description of the celestial portents and the comet, the *Sidus Iulium*, which appeared upon the death of Julius Caesar (15. 745–870).

The six books of the *Fasti*, Ovid's unfinished religious calendar in elegiac couplets, cover the year from January to June and relate stories associated with Roman holidays. The reader of the work is presumed to be conversant with the heavens, and the poet intersperses among the work's longer narratives calendrical references to astronomical occurrences. The *Fasti* likewise incorporates astral myths of many constellations, often presenting differing versions for a given star group and offering variants on the accounts in Aratus. This borrowing and adaptation is primarily a literary process (*variatio*), and at least some of the technical errors may also be attributed to the literary rather than the scientific bases of the work. Nevertheless, Ovid's so called "Eulogy of the Astronomers" (1.295–310) introduces the concepts of Stoicism, linking his work with a similar philosophical approach taken by Aratus.

The number of familiar constellations and stars in the *Fasti* is substantial, with 27 of the former traceable to those described by Aratus. The accounts vary in length and complexity, ranging from the involved to the simple, and some star groups (Hyades, Pleiades, Orion) are mentioned several times. As in the *Metamorphoses* Ovid also incorporates political and cultural themes into some of the tales. The concept of ruler catasterism, as promoted by Hellenistic monarchs and eventually supportive of the Augustan imperial program, is clearly evident in places. Most particularly this is true of the star Capella (5.111–28), to be linked ultimately to the constellation Capricorn, Augustus's own birth sign and a public symbol for the return of the Golden Age.

John M. McMahon

Alternate name

Ovidius Naso, Publius

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Ovidius Naso, Publius

➜ **Ovid**

P

Page, Thornton L.

Born **New Haven, Connecticut, USA, 13 August 1913**
Died **Houston, Texas, USA, 2 January 1996**

Spectroscopist Thornton Page, son of prominent American physicist Leigh Page, was almost a martyr to astronomy; his near-fatal fall from the 82-in. telescope platform is recounted in **David Evans** and Derral Mulholland's history of the McDonald Observatory. Page's post-world-war work on binary galaxies foreshadowed what was to become the missing mass problem. Page is known in popular circles for having participated on the "Robertson panel," convened in January 1953 by the United States of America's Central Intelligence Agency as a "Scientific Advisory Panel on Unidentified Flying Objects."

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Palisa, Johann

Born **Troppau, (Opava, Cech Republic), 6 December 1848**
Died **Vienna, Austria, 2 May 1925**

Johann Palisa was an excellent astronomical observer, discovering many minor planets whose orbits he helped to determine. He came from a poor family; his father dealt in salt. Palisa married twice. Two of his daughters married astronomers, Erna to Friedrich Bidschof, astronomer in Vienna and Trieste, and Hedwig to Joseph Rheden, a keen observer and collaborator of Palisa's. Palisa's mathematical abilities appeared quite early; after finishing school in Troppau, he began to study mathematics and astronomy at the University of Vienna in 1866. The astronomers of the old Vienna Observatory (**Karl von Littrow**, **Edmund Weiss**, and **Theodor Ritter von Oppolzer**) enabled him to earn some money doing observational and computational work. In 1870, after completing his military service, Palisa received a position at the observatory, located in the center of town, measuring positions of stars and planets with a meridian circle and making drawings of sunspots.

In 1871, Palisa worked for several months at the Geneva Observatory. He applied for and, with the recommendation of Weiss, received the position of the director of the Austrian Naval Observatory at Pola (now Pula, Croatia, on the Adriatic Sea). Palisa was responsible for time service observations and the Austrian Navy ship chronometers.

Taking advantage of the better observing conditions at Pola, Palisa took up Oppolzer's suggestion to observe minor planets with the 6-in. refractor there. The discovery of new ones by visual means required precise star charts including faint objects. Palisa used the *Bonner Durchmusterung* charts, as well as those of **Christian A. Peters** and **Jean Chacornac**, but he soon started to draw his own charts of small areas along the ecliptic. Furthermore, orbital determinations required precise positions of reference stars. For determining positions, Palisa used the Pola's 6-in. meridian circle by Troughton & Simms. In March 1874, Palisa discovered minor planet (136) Austria and by 1880, a total of 28 minor planets. He emphasized the importance of reobserving asteroids in order to secure good orbit determinations. In 1876, Palisa received the Lalande Prize of the Paris Academy of Sciences for the rediscovery of (66) Maja, lost since its discovery in 1861.

Meanwhile, a new observatory in Vienna featured a 27-in. Grubb refractor, then the world's largest. Weiss offered Palisa a position, which he accepted, giving up his rank of navy captain to become simply a member of an institute. By the end of 1880, Palisa moved to Vienna, where he received a Ph.D. in 1884. In May 1881, he discovered minor planet (220) Stephania; while in Vienna, he found a total of 93 asteroids using visual techniques. Palisa focused on determining their orbital elements and preparing star charts, using Vienna's 12-in. Clarke refractor. For over 40 years, he worked every clear moonless night. Palisa made careful notes about stellar positions in his copy of the *Bonner Durchmusterung*. In 1902, he published these notes under the title "Stern-Lexikon."

Palisa put forth his efforts into determining positions of objects recently discovered by **Maximilian Wolf** in Heidelberg and by

August Charlois in Nice. The Paris Academy of Sciences honored his work again in 1906, awarding him the Valz Prize, with **Maurice Loewy** declaring that Palisa had accomplished more in this field than other astronomers put together. Nearly every object he discovered was numbered and named, and could be reobserved during its next opposition. Only one, (719) Albert, was lost, finally rediscovered by the Spacewatch Project at Kitt Peak in spring 2000.

Palisa's style of work changed after 1892. Along with Wolf, he began to work on the production of a new photographic atlas along the northern region of the ecliptic: the Wolf–Palisa charts. Survey plates taken in Heidelberg were superimposed with precise coordinate grids prepared in Vienna. Their handy size made these prints especially valuable for direct work at the telescope. From 1908 to 1914, 180 sheets covering 50 square degree areas along the ecliptic were printed in Vienna; about 125 copies were sold. The price of each was set to earn enough money for the production of the next. World War I stopped the work; after 1918, it was impossible to sell enough copies, ending the production of these charts.

Palisa received an invitation to participate in a solar-eclipse expedition in 1883 at the Caroline Islands in the Pacific Ocean. Others in the expedition included **Pierre Jules Janssen** and **Étienne Trouvelot** from Paris and **Pietro Tacchini** from Rome. Astronomers thought they might find a new planet located between the Sun and Mercury, though the search was unsuccessful. Palisa was a government guest on board a French navy ship but had to find funding to return to Vienna *via* the United States, where he visited various observatories.

With the assistance of the Austrian emperor and the Academy of Sciences, as well as government and some private funds, he started naming minor planets he discovered in commemoration of those who supported his research.

In Vienna, Palisa was well known as an astronomy popularizer. He fascinated audiences with clear explanations of difficult problems. In 1910, he even rented the Vienna Musikvereinssaal, the concert hall of the best Viennese orchestras, to explain Halley's comet (IP/Halley) to the public. Vienna's immense growth around the turn of the century placed the observatory near the center of town, with deteriorating observing conditions. Palisa campaigned for a good telescope outside of the city, a wish left unfulfilled because of economic conditions.

After Weiss's retirement in 1909, Palisa hoped to be the Vienna Observatory's new director, but Josef von Hepperger (1855–1928), professor of theoretical astronomy, was appointed instead. For a short time, Palisa protested by giving up observing, but he could not stand to live without a telescope. He was forced to retire at the age of 71, but received special permission to continue his work and to use the observatory's equipment.

Palisa received many honors: the *Ritterkreuz* des Franz Josephs-Ordens (Austrian distinction: 1874); Lalande Prize of the Academy of Sciences, Paris (1876); Valz Prize of the Academy of Sciences, Paris (1906); Member of the Astronomische Gesellschaft (1875); *Bürger von Wien* (honorary citizen of Vienna, 1921); and Minor Planet (914) Palisana. A lunar crater (Palisa) is named in his honor.

Anneliese Schnell

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Palitzsch, Johann

Born **Prohlis near Dresden, (Germany), 11 June 1723**
Died **Leubnitz near Dresden, (Germany), 21 February 1788**

Johann Palitzsch was the first to view Halley's comet (IP/Halley) on its 1758 return. Coming from a farm family, he studied astronomy at home and attended the Mathematischer Salon in Dresden. Thanks to his recovery of Halley's comet, Palitzsch became, in 1759, instructor in astronomy to the young Elector Friedrich August III. He is reputed to have recognized Algol's variability.

Palitzsch was instrumental in introducing both the potato and the lightning rod to Saxony. A small museum honoring him is being planned on the outskirts of Dresden.

Richard A. Jarrell

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Palmer, Margaretta

Born **Branford, Connecticut, USA, 1862**
Died **New Haven, Connecticut, USA, 30 January 1924**

Margaretta Palmer obtained the first doctorate in astronomy awarded to an American woman by an American institution. (Winifred Edgerton's 1886 doctorate had been awarded by the department of mathematics at Columbia University, whereas **Dorothea Klumpke Roberts** earned the equivalent degree, a *Docteur ès Science*, from the University of Paris in 1893.) Palmer was descended from a Branford, Connecticut, family that settled there in colonial days. She attended Vassar College, New York, where she was a student of America's first woman astronomer, **Maria Mitchell**. Palmer graduated in 1887 and for the next 2 years served as Mitchell's assistant. When Mitchell retired in 1888, she pleaded with the college president to find a place for Palmer, whom she described as "remarkably faithful and conscientious." Because the college did not have funding for Palmer's salary, it has been assumed that her employment under Mitchell was sustained through private funding provided by Mitchell herself.

In 1889, Palmer began work at Yale University. She was to carry out the reductions of observations of the minor planet (7) Iris that had been acquired the preceding year. In 1892, Yale opened its graduate school to women students. Palmer took advantage of this opportunity and acquired her Ph.D. in 1894. Her dissertation dealt with an improved orbit for comet C/1847 T1, which had been discovered by Mitchell and had catapulted her to lasting fame.

In 1894, Palmer undertook an enormous computational task, unfortunately left unfinished, related to the reduction of observations of the satellites of Jupiter. She set up 1,128 observational equations of condition with 13 unknowns. Illness interrupted completion of this project. If only she could have had the benefit of modern computing facilities! She also worked on the compilation of atmospheric refraction tables for correcting the apparent positions of celestial objects to their true coordinates.

The "Yale Index to Star Catalogues" was begun under **William Elkin**'s directorship of the Yale Observatory in 1897, with the assistance of J. S. Newton, daughter of the previous director. Soon, Palmer was put in charge of this monumental task. Such an undertaking had been suggested as early as 1878 by **Arthur von Auwers** of Germany, but was not begun, as the *Geschichte des Fixsternhimmels* [GFH], until 1897. The first of 24 volumes for Northern Hemisphere stars were not published until 1922, the last in 1936, and the 24 volumes for Southern Hemisphere stars appeared between 1937 and 1952. The "Yale Index" was never published, but Palmer made it known that anyone needing astrometric data for any particular stars would be furnished references to, or the actual observations from, such sources – a service indispensable for astronomers determining the proper motions of stars.

Elkin retired in 1910, and only acting directors supervised the work started under his regime. In 1918, **Ernest Brown**, a mathematics professor renowned for his analyses of the motions of the Moon, was instructed to close the Observatory until the end of World War I. Palmer was the only employee left, and her services were considered so valuable that she was given an appointment in the college's library, working half time classifying scientific and mathematical books, and allowed to continue her astronomical research the rest of the time.

When **Frank Schlesinger** was appointed Observatory director in 1920, he found Palmer to be an ideal assistant, familiar with previous projects and especially qualified to work with him on the first general catalog of trigonometric stellar parallaxes. This too was a tremendous undertaking, but one for which her previous work on the "Yale Index to Star Catalogues" proved invaluable. Sadly, Palmer did not live to see the completion of the catalog of parallaxes. She died as a result of an automobile accident.

Palmer had been a member of the American Astronomical Society from 1915 until her death. During that interval, she gave two oral reports at meetings of the society, one in 1918 on the "Yale Index" and another in 1921 on the orbit of comet 35P/1788 Y1 (Herschel–Rigollet).

Dorrit Hoffleit

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Pannekoek, Antonie

Born **Vaasen, the Netherlands, 2 January 1873**
Died **Wageningen, the Netherlands, 28 April 1960**

Antonie Pannekoek made valuable contributions to our early understanding of the spectra of stellar atmospheres, but is best remembered for his majesterial history of astronomy. The son of Johannes and Wilhelmina Dorothea (*née* Beins) Pannekoek, he developed his interest in astronomy at an early age. As a young amateur Pannekoek was a careful and skilled observer. In 1891 he detected independently the brightness variations of Polaris (α Ursa Minoris), and was the first to determine its approximate periodicity. Concerned about the value of his data – the amplitude of variation is only 0.11 m – Pannekoek waited until 1913, when photographic and photometric data had become available, to propose the Cepheid nature of the star. Prior to his entrance into the university, Pannekoek also developed a light curve for β Lyrae and began a lifetime series of visual and photographic observations of the Milky Way. Pannekoek studied at Leiden University, where he earned a Ph.D. defending a thesis on the eclipsing system Algol (β Persei) in 1902 and acted as a staff member between 1899 and 1906. He married Johanna Maria Nassau Noordewier in 1903.

Pannekoek was launched on a successful career in astronomy when, in 1906, he had observed, independently from **Ejnar Hertzsprung**, that apparently bright red stars included some that must be substantially more luminous than others. His discovery of what later came to be known as red giants and red dwarfs was based on the significant differences between the parallaxes and proper motions of the groups of stars. Paradoxically, however, Pannekoek left astronomy to pursue his second passion, that of social justice and reform. As a political activist, one properly described as an antiauthoritarian Marxist, he spent the years from 1906 to 1914 as a teacher in Berlin, where he became one of the main leaders of the antirevisionist movement. Pannekoek contributed extensively to leftist publications in Europe and the United States. In 1914 he was deported from Germany. He returned to the Netherlands as a high school teacher while continuing his political writing and activism.

Pannekoek resumed his astronomical work in 1915, and was one of the first (in 1920) to recognize the relevance of **Meghnad Saha**'s law for deriving stellar diagnostics from spectroscopic observations. With that flash of insight, Pannekoek dropped the work he had to take up the theoretical study of stellar atmospheres and made important contributions to the field. **Marcel Minnaert** credited him with initiating the study of astrophysics in the Netherlands after Pannekoek founded, in 1921, what is now known as the Pannekoek Institute of Astronomy at the University of Amsterdam. He understood at an early date that certain line ratios in stellar spectra, which are correlated with stellar luminosity, actually probe the gravity in the stellar atmosphere. One of the striking results of his work on stellar atmospheres was his 1946 suggestion that in some pulsating stars the sound wave that moves outward converts gradually to a shock wave and ejects some material at the time of maxium radius on each pulsation cycle, a remarkably prescient suggestion that was later confirmed.

Throughout his career Pannekoek excelled in the careful measurement of astronomical information from photographic plates. The galactic studies he carried out during his early years in Amsterdam are characterized by a thorough understanding of what the eye can see on such plates. Pannekoek's knowledge of astronomical photography enabled him to pioneer, with **John Plaskett**, the quantitative analysis of photographic stellar spectra, on which the research during his later career strongly relied. Using spectra of Deneb (α Cygni) he had taken at the Dominion Astrophysical Observatory (near Victoria, British Columbia, Canada) in 1929, and a technique he invented (using log tables and mechanical calculators) for numerically integrating the equation of radiative transfer that arises from **Arthur Eddington**'s approximation, Pannekoek was the first astrophysicist to develop an empirical stellar (nonsolar) curve of growth similar to those developed for solar spectra by Harald von Klüber (1901–1978) and Minnaert. His 1930 chapter on ionization in stellar atmospheres in the *Handbuch der Astrophysik* was an important early fundamental contribution to the field. By 1935, Pannekoek had done extensive theoretical modeling of the line widths that could be expected in stellar spectra taking into account every known factor. The line widths were systematically in error, especially in cooler stars, but he predicted positions of maximum line intensity correctly. The missing factor in Pannekoek's equations was soon recognized when **Rupert Wildt** demonstrated the previously unappreciated role of negative hydrogen ions in the production of continuous absorption in cool stars.

In 1938, Pannekock made the first theoretical calculation of the widths of the Balmer series of hydrogen spectral lines applying the Stark effect to demonstrate the broadening of the wings of those lines as a function of stellar gravity. In other work, Pannekoek contributed to the understanding of metal concentrations on stellar opacity, showing that at high effective temperatures, hydrogen concentration was the dominant influence on stellar opacity and color, while at lower temperatures the effect of metallicity dominated. His analysis showed where the two effects were nearly balanced, proposing an effective temperature of about 10,500 K for stellar class A0, very nearly the value that has since been accepted.

Pannekoek's studies of the Milky Way galaxy continued for 60 years, and involved visual drawings and photographic surveys of both the Northern and Southern Hemisphere skies. He added isophote lines to show contours of brightness that have formed the basis for many popular star atlases. Pannekoek also studied the distribution of giant stars in the Milky Way using statistical approaches to the spectral parallaxes of A and K stars and spectral parallaxes of individual B stars. In this work he identified the clusters of the early stars later called associations. Pannekoek's work on the distribution of stars in the Milky Way Galaxy had a profound effect on thinking about galactic structure; his approach was later successfully applied by **Viktor Ambartsumian**, **William Morgan**, **Albert Whitford**, and Arthur Dodd Code (born: 1923).

In 1942 Pannekoek's career as professor in Amsterdam ended when he was dismissed by the German occupation forces. Until his death he remained active as a leading socialist theoretician and pursued individual astronomical studies. During and after World War II, Pannekoek's personality as both a leading scientist and a warm humanist found a remarkable expression in the historical work. His *A History of Astronomy* appeared first in 1951 in Dutch under the title *De groei van ons wereldbeeld*, which may be better translated as “The emergence of our view of the world.” His historiography reflects both of his lifetime preoccupations as he examined the history of astronomy from Babylonian to modern times in relation to the social and political systems extant in each relevant period. This remarkable book then not only offers an accurate and well-documented introduction to the history of the discipline, but also helps the modern reader to see the cosmos with the eyes of ancient people who shared with Antonie Pannekoek the delight of the beauty of the heavens. He gave full credit to Hertzsprung for distinguishing giant and dwarf stars despite his own contribution to the topic. The accuracy and insight Pannekoek offers on matters astronomical outweighs his occasional forays into political polemicism, and the book remains one of the standards in the field.

Harvard University conferred an honorary Ph.D. upon Pannekoek in 1936, while in 1951 the Royal Astronomical Society honored him for his astrophysical contributions by awarding him its Gold Medal.

Christoffel Waelkens

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Papadopoulos, Christos

Born **Prussa, (Turkey), 20 February 1910**
Died **Westcliff near Johannesburg, South Africa, 8 May 1992**

Christos Papadopoulos created what is likely to be the last great photographic atlas of the whole sky taken with one camera in one consistent sequence of well-controlled photographic charts corrected to visual magnitudes. Educated as a civil engineer in Greece, Papadopoulos fought with Greek resistance forces during World War II and then immigrated to South Africa after the war. Successful as a manager of engineering construction, he retired at the peak of his capacities to devote his time to two avocational interests: cinematography and astronomy.

Papadopoulos's greatest contribution to astronomy came in his combination of these two avocational interests in the creation of a photographic all-sky star atlas. The goal of this project was to completely photograph the sky with film and filter combinations that produced, as nearly as possible, a star atlas in which the photographic representation of the sky matched, to the greatest extent possible, the telescopic visual appearance of the sky at visual magnitudes as faint as 13.5. Similar undertakings by private individuals had previously been attempted only by **John Franklin-Adams** early in the 20th century, and again by Hans Verhenberg (1910–1991) in the middle of the same century. Neither effort was intended, however, to match the photographic representation to the visual appearance of the sky in a photometric sense.

Papadopoulos completed his Herculean task with the publication, in 1979/1980, of *The True Visual Magnitude Photographic Star Atlas*. One thousand photographic exposures of the southern, equatorial, and northern regions were taken from Papadopoulos's private observatory at his home in Westcliff, Johannesburg, and at the Stamford Observatory, Stamford, Connecticut, USA (by Charles E. Scovil). The plates were carefully matched on depth of exposure and sky brightness to produce the final atlas.

Papadopoulos was honored for this achievement by the presentation of the Astronomical Society of South Africa's Gill Medal in 1981.

Thomas R. Williams

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Pappus of Alexandria

Flourished **probably 4th century**

Primarily a mathematician, Pappus also wrote commentaries on **Ptolemy**, **Aristarchus**, and **Theodosius**, and summaries of other astronomers such as **Apollonius** and **Eratosthenes**.

Pappus's dates from the literary sources are uncertain, though he was apparently computing an eclipse in 320. His most recent cited source is Ptolemy; a scholiast puts Pappus in the reign of Diocletian (284–305); and the *Suda* has him a contemporary of **Theon of Alexandria**, and flourishing in the reign of Theodosius (379–395).

His surviving work provided and continues to provide points of departure for developments in the history of mathematics. He, with Diophantus, provided François Vieta with his point of departure in the development of algebra; one problem in Collection 7 provided **René Descartes** with his point of departure for his *Geometrie*; and Pappus's work continues to appear as starting points for articles in mathematical journals.

Credited with being halfway between compiler–commentator and originator, Pappus was fully capable of extending the work of his predecessors. His greatest – or at least most famous – individual achievement is the universalizing of Euclid 1.47, the Pythagorean theorem. Pappus further extended work of **Archimedes** and (apparently) originated the theorems that were rediscovered and named after Paul Guldin.

As reporter of the *status quo* of the mathematics of his time, it is owing to Pappus that we have the Greeks' threefold division of problems: (1) solvable with straightedge and compass, called plane; (2) solvable with one or more conics, called solid; and (3) solvable with a more complicated curve, called linear. Modern mathematicians still find this classification appropriate, though they would rename (3) and further split it into algebraic problems and transcendental problems.

Pappus's principal surviving work is the *Collection*, a treasury of all the mathematics of his time, including some of his own, in eight books. We have fragments from his other works: a commentary on Ptolemy's *Almagest*, a commentary on Euclid 10, and a geography.

The *Collection* contains such mathematical topics as arithmetic, geometric, and harmonic means, the universalizing of Euclid, the globularizing of the spiral of Archimedes, and epitomes of Euclid, Apollonius, Aristaeus, and Eratosthenes; there is also a summary of mechanics. The astronomy is in book 6, which gives commentary on Theodosius's *Spherics*, **Autolycus**'s *On the Moving Sphere*, Aristarchus's *On the Size and Distance of the Sun and the Moon*, plus Euclid's *Optics and Phenomena*.

Thomas Nelson Winter

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Parameśvara of Vāṭaśśeri [Parmeśvara I]

Born **Ālattūr, (Kerala, India), *circa* 1360**
Died ***circa* 1455**

Parameśvara, one of the foremost astronomers of Kerala, hailed from the village of Ālattūr (Aśvatthagrāma in Sanskrit), and his house, Vāṭaśśeri, was situated on the confluence of the river Nīla with the Arabian Sea. He was a *Ṛgvedin*, of the *Aśvalāyana Sūtra*, and belonged to the *Bhṛgugotra*. He was a pupil of Rudra I. He carried out astronomical observations near his house for some 45 years. He also observed a large number of eclipses between 1393 and 1432, which are recorded in his work *Siddhāntadīpikā*. Nothing else is known about the life of Parameśvara.

Parameśvara was a prolific writer and authored some 30 works. These include original treatises and commentaries on other works of astronomy and astrology. Among his original works on astronomy might be mentioned the following: *Dṛggaṇita* (1430); a work on spherics, *Goladīpikā* (1443); and three works on the computation and rationale of eclipses, *Grahaṇāṣṭaka*, *Grahaṇamaṇḍana*, and *Grahaṇanyāyadīpikā*. He also commented on a large number of astronomical works including the *Āryabhaṭīya*, *Sūryasiddhānta*, *Laghumānasa*, and *Līlāvatī*. Many of his works are yet to be published.

Narahari Achar

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Parenago, Pavel Petrovich

Born **Ekaterinodar (Krasnodar), Russia, 20 March 1906**
Died **Moscow, (Russia), 5 January 1960**

Parenago was a doyen of Russian scholars of the Galaxy and the founding father (1938) and head (until his death) of the department of stellar astronomy at Moscow State University [MSU]. Among his many accomplishments, he played a significant role in fostering astronomical observations by amateurs. His name appears in the Kukarkin–Parenago relation between the periods and amplitudes of many different kinds of variable stars.

Parenago graduated from the faculty of physics and mathematics at MSU in 1929, concurrently working at the Astronomical–Geodetic Institute, which was soon incorporated into the present-day Sternberg State Astronomical Institute of MSU (1931). In 1935, he was awarded a doctorate in the physical and mathematical sciences (without the defense of a dissertation).

Parenago's main research field was stellar astronomy, especially studies of the structure, kinematics, and dynamics of our Galaxy. He investigated the spatial distributions and kinematics of many different classes of stars, especially variable stars. These results added important parameters to the concept of stellar populations and stellar subsystems. Parenago also made an important contribution to stellar dynamics, by creating a theory of the gravitational potential of the Galaxy. His works on the stellar luminosity function, the color–luminosity diagrams for different classes of stars, and interstellar extinction in the Galaxy were widely recognized for many years. Parenago's investigations were based on statistical treatments of the large databases that he had assembled from every accessible source.

Under the auspices of the International Astronomical Union [IAU], Parenago and Boris V. Kukarkin compiled the *Obshchii* *katalog peremennykh zvezd* (General catalog of variable stars, 1948), whose later editions are still being edited at Moscow. This catalog remains the most extensive of its kind to this day. Another of Parenago's catalogs, of the stars in the Orion Nebula (1954), achieved lasting usage, being an important collection of data on this region of star formation. Parenago authored one of the early textbooks on stellar astronomy (1938), which was repeatedly revised.

In 1948, Parenago was awarded the first Bredikhin Prize, the top astronomical award presented by the Soviet Academy of Sciences. The Order of Lenin was bestowed on Parenago in 1951, and he was elected a corresponding member of the USSR Academy of Sciences in 1953.

Yuri N. Efremov

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Parkhurst, Henry M.

Born **New Hampshire, USA, 6 March 1825**
Died **New York, New York, USA, 21 January 1908**

American amateur Henry Parkhurst observed variable stars and developed an accurate theoretical–observational relationship between orbital parameters and brightnesses for asteroids. He communicated with **Edward Pickering** on matters photometric, having initiated such measurements of long-period variable stars in 1883 and publishing a volume on a decade's worth of observations in 1893. Afterward, he published in the *Astronomical Journal*.

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Parmenides of Elea

Born ***circa* 515 BCE**
Died **after 450 BCE**

Few details of cosmologist Parmenides's life are known. His dates are deduced from a story related by **Plato** that Parmenides and Zeno visited Socrates in Athens around 450 BCE, at which time Parmenides was reputedly aged about 65. An alternative chronology, ultimately deriving from **Apollodorus**, places Parmenides's birth around 540 BCE. However, this tradition is wrong and probably results from confusing Parmenides's birth with the founding of Elea.

Parmenides was the son of Pyres and appears to have originally come from Eastern Greece. He settled in Elea on the west coast of Lucania in Italy, where, according to ancient tradition, he was active in politics and renowned as a wise law-maker.

Parmenides was influenced by both **Xenophanes** and the Pythagorean Ameinias Diochaites, in whose name he erected a shrine. Indeed, in Antiquity Parmenides was considered to have been closely associated with the Pythagoreans, and in particular the Pythagorean school at Croton, southeast of Elea. Both his philosophical and astronomical ideas were similar to those of the Pythagoreans, so this connection is probably real. Parmenides founded the "Eleatic" school of philosophy, where his successors were Zeno and Melissus.

Parmenides made a greater contribution to philosophy than to astronomy. He denied that change was possible by maintaining that "what is" could not disappear, and similarly that that which does not exist could not come into existence. He denied the possibility of movement on similar grounds. He explained the apparent ubiquity of change and movement by suggesting that the senses are unreliable and do not reveal the true nature of the world. These speculations, and in particular their refutation, had profound implications on the development of Greek thought.

Parmenides's astronomical ideas are not easy to reconstruct. His surviving writings are few and fragmentary, and later sources are confused and contradictory in the views that they attribute to him. He appears to have considered the Universe to consist of a system of concentric rings or bands of fire, alternating with bands of darkness. These details come mostly from a later source, which is so heavily abridged as to be nearly incomprehensible. However, the bands are mentioned in surviving fragments of Parmenides's own writing. In the middle of the bands, guiding everything, was a divinity, personified as Justice or Necessity.

Parmenides's extant writings include the assertion that the Universe is both finite and spherical. He was not necessarily the first to hold this view, which seems to have been common among early Pythagoreans. However, his work is the first espousal of it for which the attribution is completely certain. Parmenides was speaking of the Universe as a whole, rather than just the Earth or the heavens. However, later sources misconstrue him to have said that the Earth is spherical, which his extant writings, at least, do not.

Parmenides described the Moon as an "alien light," wandering around the Earth and "always looking towards the rays of the Sun." This statement is usually taken to imply that he realized that the Moon shines by reflected sunlight. This interpretation seems reasonable, but is not undisputed. If it is correct then Parmenides is the first Greek known to hold this view. (Plato recorded that **Anaxagoras** held this opinion, but did not say that he was the first to do so.)

The extant fragments of Parmenides also mention the aether, the constellations (the signs in the aether), the Sun, the furthermost heaven, and the Milky Way, one of the first extant mentions of it in Greek.

The confused later sources attribute various ideas to Parmenides, in addition to the sphericity of the Earth, including among others, dividing the spherical Earth into five climatic zones, recognizing the Morning and Evening star as the same object, and considering the Sun, Moon, and stars as being made of compressed fire. However, these are all ideas that later sources often indiscriminately attributed to various pre-Socratics.

Unlike other early Greek philosophers, Parmenides wrote in hexameter verse rather than prose. About 150 lines of his poem *On Nature* survive, mostly through **Simplicius**, who quotes it in his commentaries on **Aristotle**. A further six lines are extant only in a Latin translation. Parmenides's ideas are described, with greater or lesser fidelity, by Plato, Aristotle, **Theophrastus,** and numerous later (and less reliable) sources.

A. Clive Davenhall

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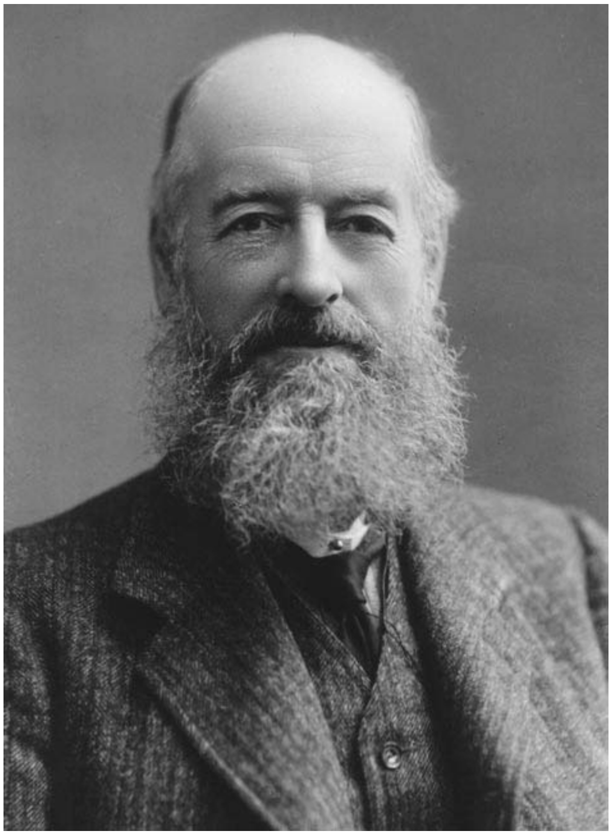
Parsons, Laurence

Born **Birr Castle, King's county (Co. Offaly), Ireland, 17 November 1840**
Died **Birr Castle, King's county (Co. Offaly), Ireland, 29 August, 1908**

Laurence Parsons, the eldest son of **William Parsons**, the Third Earl of Rosse, shared his father's enthusiasm for astronomy, continuing the study of nebulae and star clusters at Birr Castle, undertaking pioneering work on the infrared emission of the Moon and becoming the first to obtain what is now recognized as an excellent estimate of its surface temperature.



Parsons was educated at home by tutors, including the Reverend T. T. Gray and John Purser, later professor of mathematics in Belfast. The Third Earl and the Countess of Rosse took a keen interest in their children's education. The educational regimen included open-air activities on the estate and practical work in their father's well-equipped workshops. Known in his youth by his courtesy title of Lord Oxmantown, Parsons entered Trinity College, Dublin, as a nonresident student and excelled in mathematics and physics. He graduated in 1864 and immediately started to observe and sketch nebulae with the 3-ft. and 6-ft. reflectors. As a young man, Parsons had many opportunities, both in Birr and in London, to meet distinguished scientists who were friends of his father; this undoubtedly strengthened his ambition to be an astronomer.

In 1865, **Robert Ball** was appointed assistant astronomer and tutor to Laurence's younger brothers. Ball and Parsons differed by only a few months in age; they spent many nights together observing with the Birr telescopes. Parsons's first scientific paper in the *Monthly Notices of the Royal Astronomical Society* in 1866 described a water clock that he invented to drive an 18-in. equatorial telescope. His next paper, published by the Royal Society, collated all the observations of the Orion Nebula that had been made at Birr since 1849; it included an engraving of the nebula that **John Dreyer** judged as being "always of value as a faithful representation of the appearance of the Orion nebula in the largest telescope of the nineteenth century."

The Third Earl died in October 1867, and Parsons succeeded to the title and the estates. The same year, he was elected a fellow of the Royal Society and of the Royal Astronomical Society; he was also appointed High Sheriff of the county. In 1868, Parsons became a representative peer for Ireland in the House of Lords in Westminster. In 1870, he married Frances Cassandra Harvey-Hawke, only child of the fourth Lord Hawke and his second wife Frances (*née* Fetherstonhaugh).

In 1868, the Fourth Earl commenced the work for which he is best remembered, the study of radiant heat from the Moon. He was the first to make infrared measurements of any astronomical body other than the Sun. Parsons started by using a single thermocouple connected to a galvanometer but discovered immediately that the signals were affected by changes in the temperature of the 3-ft. telescope and by the ambient air temperature. He had the idea of using two identical thermocouples, connected in opposition and placed side by side in the focal plane of the telescope. One thermocouple was exposed to the Moon and the other to the sky.

At that time, no filters were available to transmit infrared radiation so Parsons used a plate of glass to block the infrared and differenced the measurements with and without the plate. He calibrated his observations by comparing his lunar measurements with those from blackened cans containing water at various temperatures. Parsons studied how the lunar radiant heat varied with the phase of the Moon and how the atmospheric attenuation varied with the distance of the Moon from the zenith. The results were summed up in his Bakerian Lecture, which he delivered to the Royal Society in March 1873. His final estimate of the lunar surface temperature was 197° F. A reanalysis of the Earl's data by William Merz Sinton (1925) in 1958 gave a value of 158° F, in good agreement with modern estimates. It was always a source of regret to Parsons that his contemporaries did not fully appreciate this achievement.

Parsons was a prolific inventor and never happier than when busy in his own workshops. As commercial thermocouples were not sensitive enough for his lunar measurements, he made his own and continued to perfect the design until a few years before his death.

Parsons was also continually trying to improve the drives of the Birr telescopes. In 1869, he fitted a clock drive to the great 6-ft. telescope that improved its ease of use but was never entirely satisfactory as the mount was not an equatorial type. In 1874, he replaced the old wooden altazimuth mounting of the 3-ft. speculum with an equatorial mounting of metal designed by B. B. Stoney and built in Dublin. While the new mount was a considerable improvement on the wooden one, it was not good enough for celestial photography.

Parsons was assisted in his investigations by a succession of talented assistants. These included Charles E. Burton, **Ralph Copeland**, Dreyer, and **Otto Boeddicker**.

The Fourth Earl took a keen interest in the development of the steam turbine, which had been invented by his youngest brother, Charles Algernon Parsons, and which revolutionized electric power generation and marine propulsion. Laurence served as chairman and director of the companies formed to exploit the invention. Charles frequently sought his advice on technical and business matters. In 1899, Laurence was made an associate of the Institute of Naval Architects in recognition of his contributions to marine technology.

Lord Rosse was elected chancellor of the University of Dublin in 1885 and remained in office until his death. He was made a Knight of the Order of Saint Patrick in 1890 and was Lord Lieutenant of King's County from 1892. Parsons served as president of the Royal Dublin Society (1887–1892) and the Royal Irish Academy (1896–1901). He received honorary degrees of DCL from Oxford (1870) and LLDs from Dublin (1879) and Cambridge (1900). The Institution of Mechanical Engineers made him an honorary member in 1888.

Following a gradual decline in health over 2 years, the Fourth Earl died and was buried in the old churchyard of Birr. He was survived by his wife and three children.

Ian Elliott

Alternate name

Fourth Earl of Rosse

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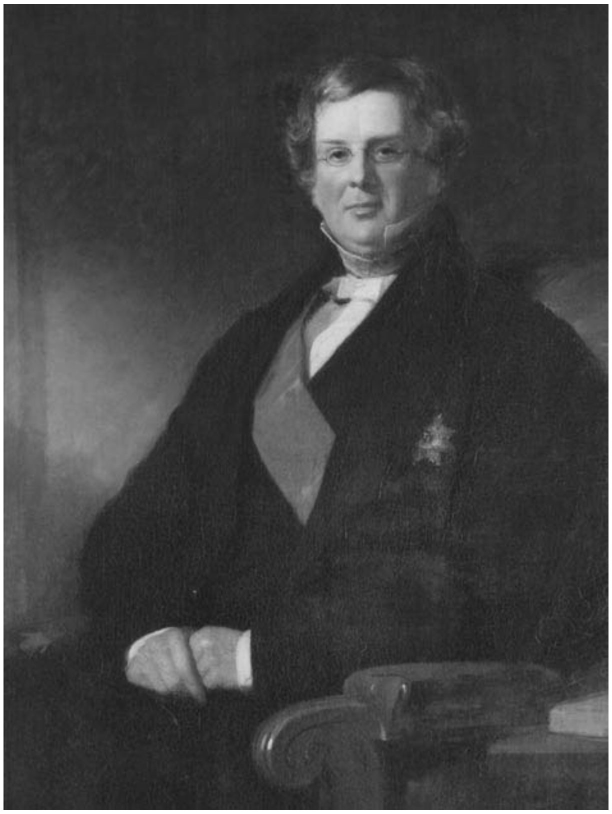
Parsons, William

Born **York, England, 17 June 1800**
Died **Monkstown, Co. Dublin, Ireland, 31 October 1867**

William Parsons, Third Earl of Rosse, a skilled engineer, ingenious scientist, and dedicated astronomer, constructed a reflecting telescope larger than any previously made, the largest in the world for seven decades. With it he discovered the spiral nature of many nebulae.



William was the eldest son of Sir Lawrence Parsons, Second Earl of Rosse and Alice (*née* Lloyd). The Parsons family came to Ireland from England at the end of the 16th century and settled in Birr, King's County (county offaly) (Parsonstown, King's County), in 1620. The Second Earl had been a prominent member of the Irish parliament since 1782, representing the University of Dublin and then his own county. With the passing of the Act of Union in 1800, his interest in politics waned and he devoted his time to the development of the town of Birr and the education of his family. William, with his brothers and his sisters, was educated at home by a series of tutors and governesses and with the active involvement of his parents.

When the title of Earl of Rosse passed to his father in 1807, William as eldest son assumed the courtesy title of Lord Oxmantown. He entered Trinity College, Dublin, in 1818 and then, with his brother John, transferred to Magdalen College, Oxford, in 1821. The following year he graduated with first class honors in mathematics. In 1823, Parsons was elected to represent King's County in the Westminster parliament; he held his seat until 1834, when he resigned in order to concentrate on his scientific interests.

Parsons became a member of the Astronomical Society of London (soon to become the Royal Astronomical Society) in 1824, just 4 years after its establishment. Through such a connection, he could have met **John Herschel**, whose father **William Herschel** had pioneered the building of large reflecting telescopes and their use in scanning the skies; in any event, Parsons and John Herschel exchanged numerous letters on astronomical matters. Parsons resolved to make a reflecting telescope as large as existing resources would allow. He could not benefit from the entire scope of knowledge of previous telescope makers, including the Herschels, for they took pains to keep some of their methods secret.

Parsons established a workshop and foundry at Birr Castle and trained his estate workers in all the practical skills that were required. After a long series of experiments to determine the optimum mixture of copper and tin for a speculum mirror, he settled on an alloy of four atoms of copper to one of tin, which he took to be in the ratio of 2.15:1 by weight. Parsons first tried making large mirrors from small segments of speculum soldered to brass plates. He invented a special machine (since widely adopted) for grinding, polishing, and parabolizing mirrors in a systematic way. The machine was driven by a small rotary steam engine of his design and made under his direction at Birr in 1827. On the strength of these achievements Parsons was elected to membership in the Royal Society in 1831. The same year he was appointed Lord Lieutenant for King's County.

In 1834, Parsons married Mary Wilmer-Field (1813–1885), the eldest daughter of a wealthy landowner who lived near Bradford, England. Mary inherited estates that were valued at £88,000 as well as a cash settlement of £8,700. Among her many interests, she became a pioneer photographer and one of the founders of the Photographic Society of Ireland.

After building a new forge, foundry, and workshop, Parsons resumed his experiments by constructing a 36-in.-diameter segmented mirror. After many trials and tribulations, in 1839 he succeeded in casting a perfect 36-in. speculum disk in one piece; it weighed 1¼ tons. A key factor in his success was the design of the casting mold, which had a base of closely packed steel strips through which gases could escape. The performance of this mirror encouraged him to attempt the casting of a 6-ft. monolithic mirror. When his father died in February 1841, William assumed the title of Third Earl of Rosse.

After many failures, two 6-ft. mirrors were successfully cast in 1842 and 1843, each weighing more than 3 tons. To avoid distortion when it was pointed in different directions, the mirror was supported by a system of 81 "equilibrated levers" suggested by **Thomas Grubb**.

The telescope tube resembled a giant barrel, 54 ft. long and 7 ft. in diameter, bulging to 8 ft. in the middle. The tube was pivoted about a huge universal joint at its base and slung with chains from two massive masonry walls, 23 ft. apart and parallel to the meridian. Horizontal movement was limited to 10° on either side of the meridian; a vertical range of nearly 110° was possible. The cost of the entire telescope was estimated between £20,000 and £30,000.

In February 1845, **Thomas Romney Robinson** of the Armagh Observatory and **James South** of London were present for the initial observations. Despite unfavorable weather, they caught a glimpse of a magnificent double star and numerous faint stars shining in M67. In April 1845, Parsons made a pencil drawing of the M51 nebula that caused a sensation when it was displayed at a meeting of the British Association for the Advancement of Science in Cambridge in June 1845. As the spiral arms suggested some sort of motion, the nebula was called "The Whirlpool." Parsons went on to discover 15 other spiral nebulae.

In autumn 1845 observational work was brought to a halt by the failure of the Irish potato crop and the resulting Great Famine. The Earl and Countess of Rosse devoted all their time and most of their income to alleviating the terrible effects of the famine. By 1848, when observations were resumed, there were many other demands on Parsons's time, so he employed a succession of able assistants, most notably **George Stoney** and **Robert Ball**. As the fame of the Great Telescope spread, visitors came from all over the world to see it and, if the weather allowed, to view the heavens.

Parsons received many honors. He was president of the Royal Society from 1848 to 1854 and was awarded its Gold Medal in 1851. He was made a knight of Saint Patrick in 1845; Napoleon III created him a knight of the Legion of Honor in 1855. Parsons was a member of the Royal Irish Academy (1822) and a member of the Imperial Academy of Science of Saint Petersburg (1852). He received honorary degrees from Cambridge (1842) and Dublin (1863). Parsons was chancellor of the University of Dublin from 1862 until his death. From 1845, he was a representative peer for Ireland in the Westminster parliament. The International Astronomical Union named the lunar crater at 17°. 9 S and 35°. 0 E in his honor.

In 1867, the Third Earl's health declined, and he took a house by the sea, just south of Dublin. He died after an operation to remove a tumor on his knee, and was buried in the old church of Saint Brendan in Birr; some 4,000 of his tenants attended his funeral.

Of the 11 children born to the Earl and Countess of Rosse, only 4 survived to adulthood. The eldest, **Laurence Parsons**, followed his father's interest in astronomy; Randal became a canon in the Church of England; Richard Clere became a successful railway engineer; and the youngest, Charles Algernon, became world famous as the inventor of the steam turbine.

After the death of the Fourth Earl in 1908, the Leviathan was partially dismantled, and one 6-ft. speculum was sent to the Science Museum in London. The great tube lay recumbent for many years until, as a result of the efforts of the sixth and seventh Earls, funding for restoration was secured in 1994. The telescope was completely reconstructed in 1996 to form the centerpiece of a historic science museum at Birr Castle.

Ian Elliott

Alternate name

Third Earl of Rosse

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Pawsey, Joseph Lade

Born **Ararat, Victoria, Australia, 14 May 1908**
Died **Sydney, New South Wales, Australia, 30 November 1962**

Australian radar and radio astronomer Joseph Pawsey led the group that, coming out of radar work in Australia during World War II, developed into one of the world's outstanding radio astronomy groups, whose early contributions included the demonstration of the very high equivalent temperature of emission from the solar corona, the precise location of the radio source Taurus A (leading to its identification with the Crab Nebula supernova remnant), and the development of interferometric and image processing techniques adopted by radio and optical astronomers and in ionospheric research and other areas. Pawsey was born to poor farming parents, Joseph Andrew Pawsey and Margaret Pawsey, in Ararat, Victoria, Australia. He did not start school until age eight, when he attended a small local school. At age 14, he received a government scholarship to attend boarding school at Wesley College in Melbourne, and then another to attend the University of Melbourne in 1926. Pawsey earned a B.Sc. (Honors) degree in 1929 and an M.Sc. (First Class Honors in Natural Philosophy) in 1931, and was granted an 1851 Exhibition Research Scholarship to Cambridge University, where he worked in the Cavendish Laboratory with J. A. Ratcliffe.

At the Cavendish Laboratory, while working toward his Ph.D., Pawsey studied the effects of the ionosphere on radio propagation. His observations of the reflection of radio waves from the E region of the ionosphere led to the discovery of irregularities, which move rapidly due to strong winds. This proved to be of pivotal importance in later ionospheric physics research.

After receiving his Ph.D. in 1934, Pawsey worked for 5 years at EMI Electronics Ltd., near London, on the design of aerials, especially the television transmitter being designed at Alexandra Palace. It was during this period that he met and married Greta Lenore Nicoll from Battleford, Saskatchewan, Canada, a marriage that resulted in two children, Margaret and Stuart, born in England, and another, Hastings, later in Australia. The time spent at EMI established him as an expert in antenna design, a skill that was used and developed later in his radio astronomy research. During this period, Pawsey was directly associated with 29 patents for devices that remained in wide use for several decades. However, only one external publication was written, due to EMI's policies to restrict access to research results.

After World War II broke out, Pawsey returned to Australia and took a position in Sydney with the Radiophysics Division of the Council for Scientific and Industrial Research [CSIR], later to become the Commonwealth Scientific and Industrial Research Organization [CSIRO]. During the war, he built up and led a team of engineers and physicists in studying radar transmission and reception and developing radar systems for the military. Because his work was classified, few publications were made public.

Pawsey had been interested in the prewar observations that **Karl Jansky** and **Grote Reber** had made, showing the existence of radio emission from the plane of the Galaxy. Although the science of radio astronomy had not yet been christened, Pawsey saw that the group he had assembled during the war could be kept intact if they could continue to study these phenomena and, encouraged by E. G. ("Taffy") Bowen, the chief of the Radiophysics Laboratory of CSIR, he led his group of researchers into this area. In 1945, using equipment that was originally part of the military defense of Sydney, located on a high cliff overlooking the ocean, Pawsey set up a radio receiving antenna operating at a frequency of 200 MHz. He used the interference between the direct rays and those reflected off the ocean to study the radio emission from the Sun, an approach known in optics as the Lloyd's mirror technique.

Two important results were published in *Nature* in 1946. The first was that intense radiation was emitted from a sunspot group, and this was so intense as to be nonthermal in origin. In that paper, Pawsey discussed the possibility of getting one-dimensional information about the source using two-beam interferometry with Fourier synthesis. This became one of the most powerful methods for studying the radio sky. The second discovery was that, at a wavelength of 200 MHz, the Sun has a lower limit of emission corresponding to a temperature of 1 million degrees. Soon afterward, from these observations, Pawsey and Tabsley established the intensity of thermal emission from the "quiet" Sun.

Pawsey's group studied the size, position, movement, spectrum, and growth and decay of various sources of radio emissions on the Sun. The group invented the swept-lobe interferometer (for location of rapidly moving sources on the Sun), the swept-frequency receiver (providing a spectrum of disturbances), and the grating interferometer, which had a resolving power of as little as one-twentieth of a degree, a much finer resolution than had been possible before. These techniques are now in general use in radio astronomy. Pawsey and S. F. Smerd reviewed much of this work in a chapter of a book on the Solar System edited by Gerard Kuiper. This, and an article written with E. R. Hill on cosmic radio waves, remained for many years essential reading for any student in the subject.

Members of the group discovered discrete radio sources in the Milky Way and external galaxies, and by accurately locating them were able to identify them optically. To achieve this, first the Lloyd's mirror technique, then two-aerial and radio-link interferometers were developed for the first time, followed by a series of linked antennas in the shape of a cross. The first survey of neutral hydrogen in the sky by the Pawsey group gave the first clear evidence of the spiral structure of our Galaxy. Again, these methods later became normal procedures in radio astronomy observatories around the world. Among the best-known members of the group were John Bolton (who located the Crab Nebula source and later built up the radio astronomy group at the California Institute of Technology) and Bernard Y. Mills, whose association with the T-shaped interferometer led to its frequently being called the Mills cross.

In 1955, with Ronald N. Bracewell, Pawsey wrote a book on radio astronomy that became the standard text in the field for many years. This was translated into Russian in 1958 with **Iosef Shklovsky** as editor. In 1962 Pawsey accepted the position of director of the American National Radio Astronomy Observatory in Green Bank, West Virginia, USA. During a visit to Green Bank in 1962 before taking up the post, he was diagnosed with brain cancer and, returning to his home, died. During his last illness, assisted by his devoted colleagues to get to his office each morning, Pawsey wrote the introduction to and edited a special radio astronomy issue of the *Proceedings of the Institution of Radio Engineers in Australia*, published in February 1963, which became a minor landmark in the instrumental aspects of radio astronomy.

Pawsey was a Foundation Fellow of the Australian Academy of Sciences (which now awards a Pawsey Medal in his honor), a foreign fellow of the Royal Society of London (which awarded him its Hughes Medal in 1960), and president of Commission 40 (radio astronomy) of the International Astronomical Union [IAU] from 1952 to 1958, in which role he played a key part in the definition of the IAU system of galactic coordinates, enabling the location of astronomical objects to be described in relation to the plane and center of the Milky Way, rather than in relation to the rotation axis and orbit of the Earth. The IAU named a lunar crater for him in 1970.

Stuart F. Pawsey

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Payne-Gaposchkin [Payne], Cecilia Helena

Born **Wendover, Buckinghamshire, England, 10 May 1900**
Died **Cambridge, Massachusetts, USA, 5 Dec 1979**

Cecilia Payne (later Payne-Gaposchkin) demonstrated in her 1925 Ph.D. dissertation that nearly all stars have the same chemical composition, with the apparent enormous differences due largely to the wide range of stellar temperatures. She also showed that this composition was dominated largely by hydrogen and helium (which was not immediately accepted) and later became a noted expert on novae and other kinds of variable stars.

Her father was Edward John Payne, a historian, barrister, and scholar at University College, Oxford; her mother, Emma Pertz, a painter and copyist in oils, was a granddaughter of Chevalier G. H. Pertz, Hanoverian scholar and member of Parliament. Cecilia

was their oldest child, soon followed by Humfry and Leonora. When her father died, Cecilia was only four, and her mother was left with three small children whom she raised "by a miracle of courage and self-sacrifice" in the environment of Edwardian England. Cecilia Payne married **Sergei Gaposchkin** in 1934, with whom she had three children: Edward Michael, Katherine Leonora, and Peter John Arthur. All three have had some involvement in astronomy.

After attending elementary school in Wendover, Payne had the opportunity to further her education when the family moved to London. Even at an early age she had learned much science independently, fascinated, for example, by the chemical elements. With a keen interest in science or possibly classics, she attended Saint Mary's College, Paddington, London, England, from 1913 to 1917 and Saint Paul's Girls School, Brook Green, Hammersmith, from 1918 to 1919.

Payne was awarded the Mary Eward Scholarship for Natural Sciences and was thus enabled to attend Newnham College, Cambridge University, Cambridge, England (1919–1923). There she first pursued the study of natural sciences with a concentration on botany, but, inspired by a lecture by **Arthur Eddington**, she changed her course of study to include more astronomy, graduating in 1923. She wrote her first paper in astronomy on the proper motions of stars in the cluster M36 in 1923.

Impressed by a lecture given by **Harlow Shapley**, then director of the Harvard College Observatory in 1922, Payne traveled to the United States for further study and in pursuit of a research career in astronomy. Payne was the first recipient of the Ph.D. in astronomy from Harvard College Observatory, which she received in 1925, as the first of Shapley's many students.

Her thesis, published as *Stellar Atmospheres*, applied **Meghnad Saha**'s is theory of ionization to establish the temperatures of the cool giants and the relative abundances of the chemical elements in their atmospheres. The first result, that nearly all stars had essentially the same abundance ratios, much like the terrestrial ratios for elements heavier than carbon, was incorporated into mainstream astronomical thinking immediately. The second result, that hydrogen and helium were by far the most common elements, was not. Shapley and **Henry N. Russell**, who had also read the work in advance of publication, recommended that Payne modify this conclusion and speak of "anomaous excitation" and a concentration of light elements on the surfaces of the stars. Nevertheless, the initial conclusion was essentially right, and has led to the thesis being described as "the best Ph.D. thesis in astronomy ever written" and Payne being described as the greatest woman astronomer of all time. Additional observations and analysis by Russell, **William McCrea**, **Carl von Weizäcker**, and others led to the accepted fraction of hydrogen and helium in the stars and Sun gradually increasing from a percent or two in 1925, to 10% in 1930, to more than 90% by 1960.

The 1920s were probably the happiest period of Payne's life. During this time she wrote several papers discussing spectral analysis and application of the Saha equation. Payne's second monograph, *The Stars of High Luminosity* (1930), established the temperature scale and uniform composition for the hotter stars of types 0, B, and A. Her collaborators included Shapley, **Leon Campbell**, **Donald Menzel**, Frederick Wright, **Fred Whipple**, and, from 1934 onward, very often Sergei Gaposchkin. On instruction from Shapley, Payne turned her attention from spectroscopy (which was to be Menzel's bailiwick) to variable stars.

Payne-Gaposchkin wrote a textbook, *Introduction to Astronomy* (1954), a monograph on *Variable Stars* (1938) with Gaposchkin, a definitive monograph, *The Galactic Novae* (1964), and an acclaimed popular account of stellar evolution, *Stars in the Making* (1953). The latter was credited by some young astronomers as their inspiration for entering the field. Her last book was *Stars and Clusters*, summarizing much that was known on this topic. She had a deep familiarity with individual stars, and even with specific spectral lines, and discussed them and recalled their characteristics as though they were friends.

In addition to her work in astrophysics and spectroscopy, Payne-Gaposchkin spent many years working with variable stars, including those enigmatic objects – the novae – and made significant contributions to the understanding of their nature. She frequently worked with photometric observations made by her husband, and they often published together. In their study of the galaxies, the Large Magellanic Cloud and the Small Magellanic Cloud, the two made roughly a million observations of variables, from which they were able to estimate the distance to these objects.

Payne-Gaposchkin was indefatigable in her research endeavors and was highly valued by her colleagues. She received her MA and D.Sc. from Cambridge University, England, in 1952. Payne-Gaposchkin also made occasional forays into history, contributing papers to the *Journal of the History of Science* and writing obituaries of several astronomers. She wrote "The Nashoba Plan for Removing the Evils of Slavery: Letters of Frances and Camilla Wright, 1820–1829" published in the *Harvard Library Bulletin*, 1975, based on a collection of letters passed down in her family.

In addition to her scientific work, Payne-Gaposchkin was an editor of the observatory publications for over a decade, and had teaching duties. Unfortunately, she suffered from overt discrimination both at Harvard and in the astronomical community because she was a woman; she was not even considered for certain positions, in spite of the extraordinary caliber of her scientific work. For example, it was not thought possible for her to make her own observations at remote observatories, as the accommodations would not permit a single woman even to visit the site. This excluded her from positions for which less talented men could readily apply.

For many years Payne-Gaposchkin had no official position at Harvard University and received a very low salary. Eventually, after the retirement of Harvard's president Lowell, she was named Phillips Professor of Astronomy. After Shapley retired as the observatory director, Payne-Gaposchkin received a professorship at Harvard, the first woman to hold this title. She then became chairman of the Department of Astronomy, the first woman to become chair of any department at Harvard University. After her retirement from this institution, she worked for some years at the Smithsonian Astrophysical Observatory, doing research exclusively.

Payne-Gaposchkin was remembered with affection and admiration by her colleagues; she was called "an astronomer's astronomer," and considered a genius. She was an inspiration to her many students and members of the general public as a role model and articulate scientist. Her sense of humor was subtle, and she was addicted to puns.

Among the honors received in Payne-Gaposchkin's lifetime were the first Annie Jump Cannon Prize of the American Astronomical Society, in 1934; honorary degrees from Smith College and elsewhere; and prizes and lectureships of the American Philosophical Society, the Franklin Institute, and the American Astronomical Society. At the latter, she was the first woman to deliver the Henry Norris Russell Prize (being introduced by the first woman to be president of the Society, E. Margaret Burbidge) in 1976. Minor planet (2039) Payne-Gaposchkin and a feature on Venus were named for her. A number of her own Ph.D. students have made important contributions to astronomy, including **Helen Sawyer Hogg**, **Joseph Ashbrook**, Elske Smith van Panhuijs, Frank Drake, Paul Hodge, and Andrew Young.

Katherine Haramundanis

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Payne, William Wallace

Born **Somerset, Michigan, USA, 10 May 1837**
Died **Elgin, Illinois, USA, 29 January 1928**

William Payne is remembered as the 19th-century founder of Goodsell Observatory at Carleton College and as the independent publisher of three popular astronomical journals. The son of Jesse and Rebecca (*née* Palmer) Payne, William earned bachelor's (1863) and master's (1864) degrees from Hillsdale (Michigan) College with proficiencies in mathematics and languages. While a teacher in the Cambria Township (Hillsdale County) schools, Payne studied law and received his LL.B. degree in 1866 from the Chicago Law School. He relocated to Mantorville, Minnesota, and formed a partnership with Robert Taylor but grew discontented in the practice. Payne returned to teaching and was chosen superintendent of Dodge County schools. He cut his editorial teeth by launching *The Minnesota Teacher and Journal of Education* (*circa* 1867–1871), which was later united with *The Chicago Teacher* to become *The Western Journal of Education*. In 1870, Payne married Josephine Vinecore; the couple had one daughter, Jessie.

In 1871, Carleton College president James W. Strong hired Payne as a professor of mathematics and natural philosophy at the college's Northfield campus. Remarkably, Payne undertook construction of an astronomical observatory, though the college, founded in 1866, consisted of but three buildings. By 1878, a small wooden observatory, housing a clock, a transit instrument, and an 8-in. Clark refracting telescope, was completed. Time signals derived from astronomical observations were first relayed by telegraph from the unfinished structure in 1877. This service, eventually the largest in the northwest, provided time for more than 12,000 miles of railroad lines. Payne influenced railroad officials to adopt standard time upon its inauguration in 1883. From 1887 to 1897, Charlotte R. Willard operated Carleton's time service. While it was under Payne's guidance, the United States Signal Corps (1881) and later the National Weather Service (1883) designated the observatory as an official meteorological station.

By the 1880s, astronomy was the most vital and important of the college's programs; Payne successfully advocated the need for more precise astronomical equipment and a larger observatory. A 5-in. meridian circle was installed, and in 1890, funds were secured for installation of a 16-in. refractor – then the sixth largest telescope in the nation. The new brick observatory was named after the college's founder, deacon Charles M. Goodsell. Its plan of work was to be threefold: "[u]ndergraduate instruction ...; a school for practical astronomy ...; and original research."

In 1882, Payne launched the first of three journals that were to spread Carleton's name throughout the astronomical community. *The Sidereal Messenger* aimed to bring an understanding of developments in astronomy to wider audiences, chiefly instructors, amateur astronomers, and the public. Sprinkled with Protestant natural theology, *The Messenger* reflected Payne's deep religious sentiments. Payne privately managed its expenses, and his subscriptions grew. When astronomer **George Hale** sought to create a research journal devoted to astrophysics, he found it necessary to compromise on a joint publication coedited with Payne. For three years (1892–1894), *Astronomy and Astro-Physics* was published at Northfield. In 1895, the University of Chicago acquired Hale's interest and the *Astrophysical Journal* was born (1895).

Many of *The Messenger*'s former subscribers found its transformation from a popular to a technical journal undesirable. Circulation of *Astronomy and Astro-Physics* actually declined even as new subscribers were added from a handful of astrophysics practitioners. To reclaim his general readers, in 1893 Payne launched another privately owned journal, *Popular Astronomy*. Subtitled "A Review of Astronomy and Allied Sciences," *Popular Astronomy* reiterated *The Messenger*'s forum on celestial events, news of the profession, essays, and a distinctive focus on pedagogy. For more than five decades, *Popular Astronomy* served as the principal channel of communication, or "trade" journal, within the American astronomical community.

In 1892, Payne represented astronomy on a subcommittee chaired by Johns Hopkins University chemist Ira Remsen. The subcommittee reported jointly to Harvard University president Charles W. Eliot and the National Educational Association's Committee on Secondary School Studies, which was popularly known as the Committee of Ten. One of the committee's recommendations was that astronomy courses should be reduced from college prerequisites to elective subjects. While seemingly an innocuous decision, its cumulative effect was to bring about a decline in astronomy education after 1900; that was an outcome strongly antithetical to Payne's own views.

Payne's teaching was conducted by the lecture-recitation method. He advocated the "mental discipline" model of pedagogy and favored adoption of textbooks that students might "read and reread thoroughly and exhaustively." One Carleton student, who punned, "He never knew pleasure, who never knew Payne," immortalized Payne's reputation as an instructor.

Additional faculty were hired to support the growth of Carleton's astronomy program, including alumni **Herbert Wilson** (1879), who succeeded Payne as editor of *Popular Astronomy* (1909–1926), and **Edward Fath** (1902). The college trained some of the era's leading women astronomers, including **Anne Young** (1892), director of Mount Holyoke College Observatory, and **Mary Byrd**, who earned a Carleton Ph.D. in 1904 and directed the Smith College Observatory. Payne received an honorary degree from Hillsdale College (Ph.D., 1894) and Carleton conferred a similar honor (Sc.D., 1916) at the college's golden anniversary.

In response to a controversy surrounding Carleton's second president, William H. Sallmon, who was himself forced to resign, Payne (along with several other faculty members) resigned in 1908. Although Payne had resigned, he was still awarded a Carnegie Endowment pension in recognition of his outstanding service to the college. The college purchased *Popular Astronomy* from Payne. After Wilson's retirement, **Curvin Gingrich** continued its publication as editor from 1926 to 1951. When Gingrich died in 1951, Carleton College elected to abandon the publication of *Popular Astronomy*.

A new demand for Payne's services arose from President Theodore Roosevelt's directive that the National Bureau of Standards conduct tests of accuracy on portable watches. In a replay of his Carleton appointment, the Elgin National Watch Company hired Payne in 1909 to establish an astronomical observatory and time service in Illinois. He retired as director emeritus of the Elgin Observatory in 1926.

Apart from his role in creating the Goodsell Observatory and Carleton's astronomy department, Payne's contributions lay chiefly in the realm of practical service and popularization. His formal training was completed before photographic plates or methods of spectral analysis were widely adopted, which may in part explain why he never conducted research. Payne recognized the prejudices that researchers associated with popularization, yet was never deterred by those prejudices. The astronomical journals that he founded and edited brought acclaim to the college that far outlasted his own services. Goodsell Observatory is listed on the National Register of Historic Places, as a site where important contributions were made to Minnesota astronomy education and the "scientific literary field" embraced by Payne's journals.

Carleton College Archives, Northfield, Minnesota, retains selected papers of Payne, chiefly in its President's Annual Reports (1873–1895), Series 42, Box 1, together with a biographical file. Payne's extensive correspondence was discarded after his departure from the college, a significant loss for the history of American astronomy.

Jordan D. Marché, II

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Pearce, Joseph Algernon

Born **Brantford, Ontario, Canada, 7 February 1893**
Died **Victoria, British Columbia, Canada, 8 September 1988**

Joseph Pearce was a stellar astrophysicist who, with **John Plaskett**, confirmed the rotation and scale of the Milky Way Galaxy. Pearce was the son of Joseph William Pearce and Clarissa Augusta Rounds. He entered the University of Toronto in 1913, but interrupted his studies in 1915 to join the Canadian army as a signals officer. After suffering wounds in France in 1916, he returned to Canada, rising to the rank of major by 1919. Pearce completed his BA at Toronto in 1920, acting as a class assistant to **Clarence Chant** during term, while working as a magnetic observer for the Dominion Astrophysical Observatory [DAO] in Victoria, British Columbia, during the summers. At Chant's insistence, Pearce obtained a research fellowship at the Lick Observatory in 1922 and began his Ph.D. studies with **Robert Aitken**. In 1924, Plaskett required a replacement at the DAO and, on Aitken's recommendation, Pearce was hired, despite not having finished his degree. It was not until 1930, after much prodding by Plaskett, that he obtained the Ph.D. Pearce married Esther Mott in 1917, and they had two children, Josephine and Richard. Esther Pearce died in 1945, and he married Elizabeth Allan in 1947.

Plaskett had completed his survey of O stars when Pearce arrived and recruited him to work on the B-star program, a survey of all B stars brighter than magnitude 7.5 and north of declination −11°, altogether some 1,056 stars. The work was undertaken with the DAO's 72-in. reflector. Plaskett had keenly followed the work of **Bertil Lindblad** and **Jan Oort** on the possible rotation of the Galaxy and had conferred with Oort in Leiden in 1927. Although the B-star survey was incomplete – it would be finished in early 1929 and published in 1930 – Plaskett and Pearce had sufficient data to test the theory. With useful data for about 500 O and B stars, they were able to locate the galactic center near to where Oort found it and near the point **Harlow Shapley** indicated from his globular cluster measurements. Plaskett and Pearce published their preliminary results in the *Monthly Notices of the Royal Astronomical Society* in 1928 and their final results in the *Publications of the Dominion Astrophysical Observatory* in 1930. They calculated a galactic rotation speed of 275 km/s at the distance of 10 kpc from the galactic center.

The O- and B-star data also provided Plaskett and Pearce with the possibility of solving the problem of the location and motion of the interstellar gas. **Arthur Eddington**, in 1926, argued that interstellar calcium was spread throughout the Galaxy in clouds that were relatively stationary as stars moved through them. Ca II lines would show up only in very hot stars. By 1929, possibly with preliminary data from Plaskett and Pearce, **Otto Struve** and **Boris Gerasimovic** posited that interstellar calcium did move, but at half the rate of the stars. In 1930, Plaskett and Pearce, with their extensive data, showed that this seemed to be the case. Plaskett retired in 1935, and Pearce embarked upon an expanded B-star program with Robert M. Petrie, adding stars brighter than magnitude 9 and north of declination +20°. The final results did not appear until 1962. Pearce, like other DAO staff, computed a number of spectroscopic binary orbits, and observed stars in the Pleiades and Hyades. Few of these results were published.

Pearce became assistant director of the DAO in 1936 and director in 1940 on **William Harper**'s death. He held the position until 1951, when he turned over the reins to Petrie. Pearce remained on staff until 1958, when he retired.

Pearce was a long-time supporter of the Royal Astronomical Society of Canada, being a key figure in the Victoria Centre and a member of the national council for a decade, culminating in his tenure as president in 1940. He was also a vice president of the American Astronomical Society in 1943/1944, and a member of the American Association for the Advancement of Science, the Astronomical Society of the Pacific, and the Société Astronomique de France. He was a fellow of the Royal Society of Canada (president 1949/1950). Like other DAO staff members, Pearce was a contributor to International Astronomical Union commissions, as a member of Commissions 27, 42, and 30 (Radial Velocities, of which he was president from 1948 to 1952).

Richard A. Jarrell

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Pearson, William

Born **Whitbeck, (Cumbria), England, 23 April 1767**
Died **South Kilworth, Leicestershire, England, 6 September 1847**

Reverend Dr. William Pearson cofounded the Astronomical Society of London (now the Royal Astronomical Society [RAS]), made a number of elaborate astronomical clocks and demonstration instruments, and published a valuable treatise on practical astronomy. The son of yeoman farmer William and Hannah Pearson, the younger William pursued his education and career vigorously in spite of his modest origins, spending the first half of his working career as a highly successful schoolmaster, and then evolving as a beneficed clergyman in his later years.

As an amateur astronomer who was active in the astronomical community at the beginning of the 19th century, Pearson's earliest astronomical interests appear to have been focused strongly on the design and construction of clocks, orreries, and planetary machines. Well acquainted with instrument maker Edward Troughton (1753–1836), Pearson utilized gears with substantially more teeth than the standard horological practice of the day and produced smoothly functioning and effective clocks, watches, and demonstration machines. Pearson's interest in observational astronomy flourished in later years, leading to the publication of his *Practical Astronomy*, which was more appreciated in the decades after his death than after its publication in 1829.

Thomas R. Williams

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Peary, Robert Edwin

Born **Cresson, Pennsylvania, USA, 6 May 1856**
Died **Washington, District of Columbia, USA, 20 February 1920**

Robert Peary, Arctic explorer and naval officer, was the son of Charles Nutter Peary and Mary (*née* Wiley) Peary. Peary's father died when he was 2 years old, leaving him to be raised by his mother, who had a strong influence on his life. Peary attended Portland (Maine) High School and then Bowdoin College, from which he received a degree in civil engineering in 1877. For 2 years, he worked as a surveyor at Fryeburg, Maine, before joining the United States Coast and Geodetic Survey as a draughtsman. In 1888, Peary married Josephine Diebitsch of Portland, and the couple had two children.

Peary was commissioned as a civil engineer in the United States Navy from 1881 to 1891. His interest in Arctic exploration developed from a private trip he made to Greenland in 1886. On several of his later expeditions, he was accompanied by his wife. Peary decided to use northern Greenland (and its coast) as points of departure for trying to reach the North Pole. He made observations of the Sun to determine his positions and set several new records for northern latitude, including Greenland's northernmost point, Cape Morris Jesup.

Peary's final push toward the North Pole began in 1908, with support from the National Geographic Society and other private patrons. Peary's claims to have reached the North Pole in April 1909, ahead of competitor Frederick Cook, were widely accepted in his day. For his reputed accomplishment, Peary received worldwide recognition and a number of awards, including a Gold Medal from the Congress. However, these claims have not stood up to later scrutiny, and substantial discrepancies exist in Peary's account. Most polar authorities no longer accept Peary's assertion to have reached the North Pole, or many other alleged discoveries.

During an earlier Greenland expedition, Peary recovered three massive fragments of an iron meteorite from the Cape York shower. These are known from Eskimo folklore as "The Tent," "The Woman," and "The Dog." Peary's wife later sold these meteorites to the American Museum of Natural History, where they remain on display.

Peary's popular writings, which described the numerous hardships, trials, and disappointments he experienced, nonetheless served to inspire later generations. He was buried at the Arlington National Cemetery. Peary's collections are housed in the National Archives, but they were not publicly opened until the 1980s.

Raghini S. Suresh

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Pease, Francis Gladhelm

Born **Cambridge, Massachusetts, USA, 14 June 1881**
Died **Pasadena, California, USA, 7 February 1938**

American optician and spectroscopist Francis Pease is most widely remembered for his contributions to the design and construction of the 60-, 100-, and 200-in. telescopes at Mount Wilson and Palomar observatories, but he also obtained the first accurate rotation curves of spiral galaxies and with **Albert Michelson** made the first direct measurements of the diameters of stars other than the Sun. Pease graduated from the Armour Institute of Technology in Chicago (now part of the Illinois Institute of Technology) in 1901 with a BS in mechanical engineering, and received honorary MA and Sc.D. degrees from the institute in 1924 and 1927. While a student, he worked evenings at the Petitdidier optical shop, and his employers recommended him to **George Ritchey**, the chief optician at Yerkes Observatory. Ritchey's father had also been one of Pease's teachers at Armour. Thus, with Ritchey, **Walter Adams**, and **Ferdinand Ellerman**, Pease moved west with **George Hale** in 1904 as one of the founding staff members of Mount Wilson Observatory. He remained there the rest of his life, apart from a year of war work in 1918 as chief draftsman in the engineering section of the National Research Council.

The history of astronomy has focused more closely on discoveries and theories than on the instruments used to make them and verify them; Pease's reputation as an astronomer consequently is less than it might otherwise have been. On the other hand, his role at Mount Wilson Observatory has been somewhat exaggerated, at the expense of Ritchey's reputation. Even before Ritchey was fired in 1919, Hale, the Mount Wilson director, had worked to make Ritchey an "unperson," preventing him from receiving outside recognition. Pease customarily is credited in whole or in large part for many of the instruments at Mount Wilson and Mount Palomar observatories, including the 60-inch 100-inch and 200-inch reflecting telescopes, the 60-foot and 150-foot tower telescopes, and the 20-foot and 50-foot interferometers. Actually, Ritchey led the work on the 60-inch reflecting telescope, and also on the 100-inch until November 1912, when Pease was placed in charge of the design for its mounting. Even then, Ritchey continued to figure the mirror.

Pease also made observations with the instruments at Mount Wilson Observatory. Not only did his observing experience contribute to his design skills, but some of Pease's observations were significant in themselves. During August, September, and October of 1917, he managed to take a 79-hour exposure of the Andromeda Nebula (M31). From the spectrograms taken with this exposure, and from an even longer one of 84 hour made a year earlier by Adams, Pease confirmed the spectroscopic rotation of the nebula.

From 1917 through 1919, working with the 60-inch reflector at Mount Wilson Observatory, Pease took some 66 plates of the spiral nebula M33. A nova appeared on four of the plates, and its observed magnitude was consistent with the distance to the nebula determined by **Edwin Hubble** from Cepheid stars also found in the nebula.

In 1928 Pease was the first to identify a planetary nebula in a globular cluster (M15). Previously cataloged as a star, the planetary nebula is now named Pease 1. It was, for many years, the only known planetary in a globular cluster, and they are still very rare.

Pease's most famous astronomical discovery was the first measurement of the diameter of a star other than our own Sun. Physicist **Albert Michelson** redesigned his stellar interferometer, and in the summer of 1920 had it mounted on the 100-inch reflecting telescope at Mount Wilson Observatory. He had to return to the University of Chicago at the end of the summer, and left Pease in charge of the measurements. In December Pease reported success, having determined an astounding diameter of 240 million miles for the star Betelgeuse.

A decade later Pease built a 50-foot interferometer, potentially capable of measuring stellar diameters half the size of what the 20-foot interferometer had measured. However, the instrument was not a complete success; thermal gradients allowed deflections in the support beam, which in turn allowed unacceptable fluctuations in the optical path lengths from the outer mirrors to the eyepiece.

Pease also worked with Michelson on a more accurate determination of the velocity of light. The measurements were begun in the summer of 1922 and continued over subsequent summers, to and beyond Michelson's death in May 1931, first between Mount Wilson and Mount San Antonio (1924–1938) and later on the Irvine Ranch in Orange County, California (1930–1934).

Although Pease was a member of most of the renowned astronomical societies, he received no major awards and held no major offices in them. In 1905, he married Carline T. Furness, who must not be confused with **Caroline Furness**, director of Vassar College Observatory for many years. Pease's most ambitious telescope design was surely the 300-inch one made in 1926.

Norriss S. Hetherington

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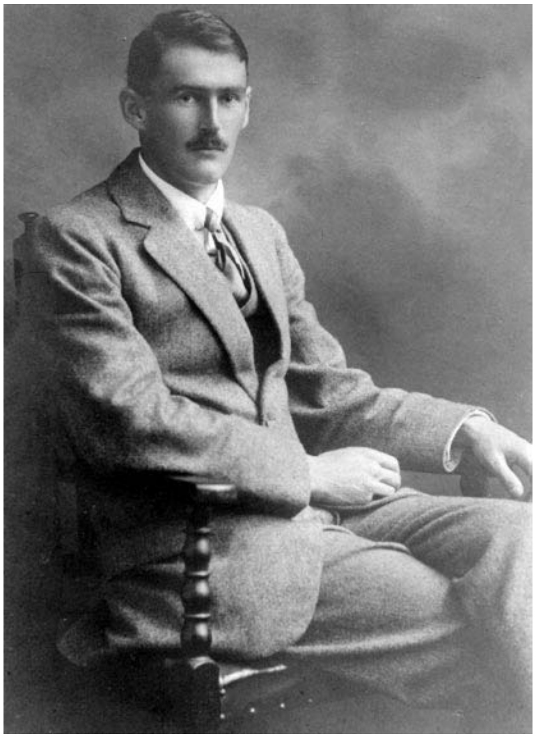
Peek, Bertrand Meigh

Born **Boscombe, Dorset, England, 27 December 1891**
Died **Melbourne, Victoria, Australia, May 1965**



Bertrand Meigh Peek is best remembered as the author of many of the Jupiter *Memoirs* of the British Astronomical Association [BAA] and especially of the classic book *The Planet Jupiter*.

Peek had a traditional English upbringing through private schools and the University of Cambridge, where he was a three-time winner of the mathematics prize and a tennis champion. His highest degree at Cambridge was an MA. Peek rose to the rank of major in the British army, serving with The Hampshires Regiment in India during World War I. After the war, Peek took up a career as a teacher, and became headmaster of a school in Solihull, Birmingham, England. Peek's other avocational activities included a continued involvement in sports, chess (a member of the Anglo–Soviet match teams), and music – he composed at least one symphony. He was an early amateur radio operator.

Although Peek was interested in many fields of amateur astronomy, and contributed results to the Double Star and other BAA sections, it was his lifelong interest in planetary astronomy that produced his greatest contributions. Peek was briefly director of the BAA's Mars Section and then Saturn Section. In 1933, while director of the Saturn Section, Peek carried out an exhaustive mathematical analysis of the motions of **William Hay**'s white spot on Saturn. Then, in 1934, he swapped posts with the then director of the Jupiter Section, Reverend **Theodore Phillips**, who had done so much to direct amateur observations to form a scientifically reliable body of work. Like Phillips, Peek maintained an active correspondence with many amateur astronomers, including Hugh M. Johnson (born: 1923) and **Walter Haas**, active observers in the United States who, as Peek noted, helped sustain the work of the section during World War II.

Often Peek would visit Phillips's observatory to observe with him. Peek continued Phillips's high standards both of observation and of analysis. He insisted on a careful scientific approach to his own and others' observations, taking care to exclude subjective effects and emphasizing numerical results – particularly the Jovian wind speeds that could be deduced from visual transit measurements. Although color changes on Jupiter are perhaps an equally important phenomenon, of which Peek made careful observations, he became skeptical of the possibility of reaching reliable conclusions from these subjective impressions and therefore devoted little attention to Jovian colors in his writings.

Peek retired from the directorship of the BAA Jupiter Section in 1949, when his health declined, then embarked on writing *The Planet Jupiter*. In this book, only the second book published on Jupiter, he summarized the observed phenomena of the atmosphere, with notably lucid narrative and occasional dry wit. *The Planet Jupiter* was the definitive text for a generation until spacecraft visited the planet. Peek's health recovered somewhat, and he resumed observing to codiscover the 1955 South Tropical Disturbance.

An active participant in BAA affairs, Peek served as the BAA president from 1938 to 1940, and the association owed much to his leadership and stabilizing influence during World War II.

John Rogers

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Peirce, Benjamin

Born **Salem, Massachusetts, USA, 4 April 1809**
Died **Cambridge, Massachusetts, USA, 6 October 1880**

Benjamin Peirce established an American presence in celestial mechanics, trained a number of leading astronomers, and played an important role in the development of the institutional structure of American science.

Peirce was the son of Benjamin and Lydia Ropes (*née* Nichols) Peirce. The Peirces were among the oldest families in the United States; Peirce's ancestor, John Pers of Norwich, England, came to the New World in 1637. Peirce attended the Salem Private Grammar School where he became acquainted with **Nathaniel Bowditch**, father of his classmate Henry Ingersoll Bowditch. Peirce entered Harvard University in 1825, at a time when the university was in a dire financial crisis. When Nathaniel Bowditch became one of Harvard's trustees the next year, he forced a thorough reorganization of the university, including the dismissal of a mathematics professor whose grasp of mathematics, according to Bowditch, was less than that of "Peirce of the Sophomore class." Recognizing the capability of the young Peirce, Bowditch employed him to help read proofs of his translation of **Pierre de Laplace**'s *Traité de méchanique céleste*.

After graduating in 1829, Peirce taught for 2 years at a private school before becoming a tutor in mathematics at Harvard University in 1831. Appointed temporary head of the Department of Mathematics in 1832, Peirce became permanent head of the department when his predecessor retired for medical reasons. Peirce received his MA in 1833, and was appointed a professor of mathematics and natural philosophy. In the same year, he married Sarah Hunt Mills. They would have a daughter and four sons, including two, James Mills Peirce and Charles Sanders Peirce, who would themselves become mathematicians.

Peirce was active in computing the orbits of comets and developing the mathematics of perturbation functions in celestial mechanics. In 1842, he was appointed Perkins Professor of Mathematics and Astronomy. His public lectures on the great March sungrazing comet C/1843 D1 helped stimulate public support for expansion of the Harvard College Observatory and acquisition of the 15-in. Merz and Mahler refractor, at that time one of the world's three largest refractors. Peirce was the first in the United States (1848) to give lectures in celestial and analytical mechanics.

Peirce's interest in celestial mechanics would lead him into several controversies. After **Urbain Le Verrier** and **John Adams** discovered that the irregularities in the motion of Uranus could be accounted for by assuming the existence of a hitherto undiscovered planet, and made detailed predictions of where such a planet might be found, on 23 September 1846 the German astronomer **Johann Galle** discovered Neptune in very nearly the position predicted by Le Verrier. However, Le Verrier's predicted distance was far in excess of the actual distance, which led Peirce and United States Naval Observatory astronomer **Sears Walker** to conclude that the discovery of Neptune, far from being a triumph of celestial mechanics, was in fact little more than a coincidence. This contention was bitterly disputed on both sides of the Atlantic and added to an already intense debate over Le Verrier's priority in comparison to Adams.

At about the same time, Peirce's activities expanded to include administrative affairs of the university as well as the institutional structure of science in the United States. In 1846, he was asked to draw up a plan for what became Harvard University's Lawrence Scientific School. Peirce was a member of a committee that drafted and distributed the constitution of the American Association for the Advancement of Science [AAAS] as that organization emerged from the American Association of Geologists and Naturalists in 1848. In these activities, Peirce joined with other influential figures in mid-19th-century American science such as **Joseph Henry**, first director of the Smithsonian institute; **Alexander Bache**, director of the United States Coast Survey; and others who corresponded and met frequently. In their correspondence they described themselves as the "scientific Lazzaroni." In residence primarily in Cambridge and Washington, and well connected politically and socially to elites in both centers of American culture, the Lazzaroni tended to act in concert on matters involving the institutional structure of science in America.

Peirce's connections with the Lazzaroni would lead him to another controversy. In 1856, as part of the Dudley Observatory's scientific council, Peirce found himself in the midst of a power struggle. The scientific council, consisting of Peirce, Bache, Henry, and **Benjamin Gould**, first director of the Dudley Observatory, had coordinated a plan of detailed astronomical observations with the Coast Survey. However, Gould's delays in implementing the plan and demands for further improvements in the observatory created a major feud between the scientific council and the observatory's trustees over governance of the institution. The trustees prevailed; in 1859, the scientific council was effectively dissolved.

Peirce did not abandon his teaching and scientific pursuits during these years of external involvement. In a paper presented orally at a meeting of the AAAS in 1851, Peirce showed that Saturn's rings could not be solid, but must instead be fluid. Peirce's paper credited **George Bond** of Harvard College Observatory with reaching the same conclusion observationally the previous year, but failed to mention that Bond offered a mathematical argument to support his observations, leading to yet another acrimonious dispute. It would be several years before **James Maxwell** demonstrated theoretically that the rings must be solid particles rather than a fluid. Peirce's students at Harvard University included the astronomers **George Hill**, **Percival Lowell**, and **Simon Newcomb**. Peirce was responsible for Newcomb's postgraduate commissioning as professor of mathematics at the United States Naval Observatory.

Peirce considered himself a candidate to replace **William Bond** as director of the Harvard College Observatory when the latter died in 1859. That placed him in direct competition with the younger Gould, who had been forced to resign at Dudley Observatory, as well as with Bond's son George, who was selected to fill the post. Peirce's candidacy disrupted his previously friendly relationship with Gould irreparably.

Peirce shared with other Lazzaroni members a desire for a more exclusive national venue in which leading scientists might share their research and influence national science policy. In 1863, he joined with Bache, Louis Agassiz, and Gould to work with US Senator Henry Wilson in writing the congressional act that established the National Academy of Sciences. Peirce was, of course, one of the 50 elite scientists selected for initial membership in the academy. The fact that Bond, his rival at Harvard, was not among the 50 scientists contributed to their continuing animosity.

In 1867, Henry prevailed upon Peirce to accept appointment as the director of the United States Coast Survey after Bache's death. Gould had been working part-time for the Survey as director of longitude determination since 1852. In that year, he published a statistical method for discarding discrepant observations that was widely adopted as Peirce's criterion but was later discredited. Peirce's 1870 work on linear associative algebra is considered the first major original contribution to mathematics produced in the United States and marks the beginning of the acceptance of American mathematics as a field separate from astronomy by European mathematicians. Peirce was highly effective as an administrator of the Coast Survey until he returned to full-time teaching at Harvard University in 1874.

Peirce was honored on both sides of the Atlantic with membership in scientific societies: He became a member of the American Philosophical Society and one of 50 foreign members of the Royal Society of London in 1852, a fellow of the American Academy of Arts and Sciences in 1858, and an honorary fellow of the University of Saint Vladimir in Kyiv in 1860. When Peirce died, his pallbearers included James Joseph Sylvester, J. Ingersoll Bowditch, Newcomb, and Oliver Wendell Holmes, a Harvard classmate who later wrote a tribute to Peirce.

Jeff Suzuki

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Peiresc, Nicolas-Claude Fabri de

Born **Belgentier, (Var), France, 1 December 1580**
Died **Aix-en-Provence, (Bouches-du-Rhône), France, 24 June 1637**

In addition to fostering scientific correspondence, Nicolas Peiresc discovered the Orion nebula and tracked the satellites of Jupiter in order to solve the longitude problem. He was the son of Réginald Fabri, descendant of a Pisan family, and Margareta Bomparia, both of whom represented notable Provencal lineages and connections. After Peiresc attended Jesuit schools in Aix and Avignon, his father and uncle sent him on an extended trip to Italy (1599–1602) to prepare him further for the family post in the parliament of Provence. During his first year in Italy, Peiresc studied in Padua, where he met **Galileo Galilei** before settling in Montpellier to study law. After finishing his legal studies there, Peiresc attained a doctorate degree in civil law in Aix (1604). When his uncle died on 24 June 1607, leaving open the family *parlement* position, Peiresc immediately filled the seat and held it for 30 years until his own death. For much of his adult life, Peiresc was at the center of an important correspondence network as a mediator to whom others looked for diplomatic solutions. For example, when Galilei was put under house arrest, Peiresc warned Cardinal Barberini that the failure to change Galilei's verdict might yield a comparison with Socrates' trial and similar condemnation.

Among his many interests and activities, Peiresc dedicated time to astronomical observations. In November 1610, while repeating some of Galilei's observations published in *Sidereus Nuncius*, Peiresc and cleric Joseph Gaultier de la Valette (1564–1647) were apparently the first to observe a nebula in the constellation of Orion. Peiresc also observed the moons of Jupiter with the help of Gaultier and mathematician **Jean Morin**, and subsequently wrote a commentary he never published.

Peiresc's most important and practical astronomical contribution stems from his work on longitude calculations. The main problem of determining longitude involves finding an accurate timekeeper. In the early 17th century, the regular motions in the heavens provided the most accurate clock. Peiresc originally planned to use the satellites of Jupiter as that celestial clock. Between November 1610 and May 1612, Peiresc made regular observations of the Jovian moons. Near the end of this period of observation, Peiresc felt his calculations were adequate enough for testing. He sent his assistant Jean Lombard to make observations of the moons of Jupiter in locations as far away as North Africa, Malta, and the Levant. The local time difference between the appearance of a configuration of Jupiter's satellites as they appeared in Aix (according to Peiresc's tables) and the appearance of that same configuration observed in Malta (by Lombard) could be used to calculate the difference in longitude between the two locations. After Lombard's mission failed due to the difficulty of this technique, Peiresc largely abandoned work in astronomical observations for 16 years.

Between 1616 and 1623, Peiresc lived in Paris, where he met and associated closely with the circle of thinkers surrounding the librarians Pierre and Jacques Dupuy. It was through the Dupuy brothers that Peiresc met **Marin Mersenne** and others. Peiresc never married; his relationships did not extend beyond the intellectual friendships he had with such men as the Dupuy brothers and Mersenne. In 1618, Louis XIII granted Peiresc the abbacy of a monastery in Guîtres, north of Bordeaux, making Peiresc's ties to the church stronger and his distance from marriage further. Peiresc returned to Aix in the summer of 1623; in the next year, he took the tonsure in order to regularize his position as abbé of the Guîtres monastery.

By 1628, Peiresc again took up the task of establishing longitude positions from his home in Aix, but with a different plan. He determined to use observations of lunar and solar eclipses made in different cities to establish the separation of longitude between them. To begin this new project, he requested others (among them the Dupuys) to send him observations of eclipses that occurred in January and February of 1628. He later distributed the observed times of the eclipses, which could then be compared to astronomical tables. According to the observations made in Paris and Aix in 1628, Peiresc calculated that the separation in longitude between the two cities was 3° 30′ 2″ greater than the previous standard.

Because of plague and public unrest between 1629 and 1631, Peiresc temporarily abandoned Aix for his country home in Belgentier, where he was unable to continue his astronomical observations. In 1632, Peiresc returned to Aix, where he resumed his telescopic observations and his larger project of gathering observations of eclipses from diverse locations in order to make longitudinal calculations. To aid him in this project, he recruited priests and Jesuits stationed in various locations from Rome to Mount Sinai. Despite the condemnation of Galilei in 1633, Peiresc explained to his recruits that making observations would not bring harm to souls and could even encourage others to follow in their footsteps.

For making eclipse observations, Peiresc stressed the need to use a telescope, but the network of observers he assembled did not always perform as he wished. Complications included letters and instruments lost in the mail, bad weather, sick observers, and faulty clocks – a crucial problem given the importance in determining the precise time of any given observation. These and other difficulties made Peiresc's task of compiling observations all the more difficult. He was, however, able to find some success with a lunar eclipse on 28 August 1635; it resulted in correcting, and reducing by about 1,000 km, the length of the Mediterranean found on contemporary maps. To further increase the accuracy of such observations, Peiresc, along with the help of **Pierre Gassendi** and others, established the Provençal school of astronomy, where he could instruct future observers and achieve more uniformity in his project. However, after his death, the school folded, with most of the remaining students and teachers moving to Paris.

Derek Jensen

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Pèlerin de Prusse

Born **Chelm (Chelmno), Poland, mid-to-late 1330s**
Died **after 1362**

Pèlerin de Prusse is known less for his original work than for disseminating knowledge of astronomy and astrology. He studied at the University of Paris under the direction of the well-known scientist and mathematician **Albert of Saxony**, and graduated as master of arts by 1359. In that year Pèlerin requested and received permission from the University of Paris to deliver "extraordinary lectures" (public lectures given outside ordinary lecture hours) on a book that may have been about either astronomy or astrology: The document referring to the lectures uses the equivocal Latin word *astrologia*, and the book to be lectured on is not specified. It is perhaps worth noting that Pèlerin's associate Robert le Normand had in the previous year been given similar permission for extraordinary lectures on **Ptolemy**'s astrological *Tetrabiblos* and on the pseudo-Ptolemaic *Centiloquium*, also astrological.

No doubt on the basis of his academic work, Pèlerin was soon appointed court scholar to Charles, Duke of Normandy (later King Charles V of France). He was but one of a number of astrologers–astronomers associated at one time or another with Charles' court, but he seems to have been especially favored. Court records call him Charles' "beloved clerk," and Pèlerin was in the early 1360s installed in his own rooms, with his manservant, in Charles' new palace, the Hôtel Saint-Pol.

Two surviving works by Pèlerin testify to the nature of his contributions to astronomy. One is the *Livret de elecions* (1361), an astrological treatise with some astronomical side benefits, such as the promotion of a relatively new and sophisticated instrument, the planetary equatorium. The other work, the *Practique de astrolabe* (1362), is on a more familiar instrument, the planispheric astrolabe. The *Practique* is a strictly astronomical work, based largely on a Latin treatise said to have been translated from the Arabic of **Māshā 'allāh ibn Atharī**. Pèlerin expressly, and accurately, disclaims any originality for his work. His role is to put knowledge of the stars into French at the command of Charles, who was at the time sponsoring similar efforts by other scholars, including the above-mentioned Le Normand as well as the famous scholar-bishop **Nicole Oresme**. The same kind of vernacularizing role was played later by the English writer **Geoffrey Chaucer**, whose *Treatise on the Astrolabe* (*circa* 1391) was also based on Māshā 'allāh. What George Sarton says about Chaucer can be said with equal justice about Pèlerin: "the study of [his] scientific knowledge is important not so much from the point of view of the history of science *stricto sensu*, but rather for the understanding of popular diffusion of scientific ideas of his time."

Pèlerin's date of death is inferred from the date of his last known written work.

Edgar Laird

Alternate names

Preussen, Pilgrim Zeleschicz von
Peregrinus de Prussia

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Peltier, Leslie Copus

Born **near Delphos, Ohio, USA, 2 January 1900**
Died **Delphos, Ohio, USA, 10 May 1980**

As a prolific variable star observer as well as the independent discoverer of 12 comets and six novae in over six decades of observing, Leslie Peltier established himself as the leading amateur astronomer of his time. His autobiography, *Starlight Nights*, lead countless readers into astronomy. **Harlow Shapley** called him "the world's greatest non-professional astronomer."

Peltier was born to Stanley W. Peltier, a strawberry farmer and distributor, and Resa (*née* Copus) Peltier, a schoolteacher. Both parents were avid readers; their home was filled with books on many subjects. Peltier's love of books, reading, and his woodworking, designing, and architectural skills were absorbed from his parents.

Peltier's elementary education in a one-room schoolhouse was typical of the time. Living on a farm gave him the independence to study and observe whatever interested him as he went about his farm chores. He taught himself the geology, flora, and fauna of the Delphos area. At 5 years of age, through the kitchen window Peltier had noticed bright stars in the night sky, which his mother identified as the Seven Sisters, or Pleiades. But it was not until a dark night 10 years later that Peltier suddenly realized that he knew much about many aspects of nature but not about the stars. That night marked the beginning of his avid interest in astronomy. The librarian at the Delphos Public Library suggested that he read Martha Evans Martin's *The Friendly Stars*. Using this simple but well-written book, Peltier learned about the bright stars starting with Vega.

Peltier purchased his first telescope, a 2-in. French spyglass, with 18 dollars that he earned by picking 900 quarts of strawberries on the family farm for 2 cents per quart. The telescope had a focal length of 36 in. with eyepieces for 35× and 60× magnification. Thus began the long and successful observing career that would span more than six decades.

The next book Peltier consulted was **William Tyler Olcott**'s *A Field Book of the Stars*. Olcott invited those with small telescopes who were interested in assisting professional astronomical research to write to him. Peltier wrote immediately; Olcott's response described the systematic observations of variable stars by the American Association of Variable Star Observers [AAVSO], and included an AAVSO application. When Peltier returned the application, he received charts and instructions for observing. On 1 March 1918 Peltier made his first variable star observation of R Leonis. On 1 March every year thereafter, Peltier observed R Leonis in commemoration of that first observation. Beginning with his first report, for March 1918, Peltier sent consecutive monthly reports to the AAVSO until his death, never missing a single month. Peltier's monumental total of 132,123 observations will insure that he remains among the leading variable star observers of all time.

In November 1918, the AAVSO offered to loan Peltier a 4-in. Mogey refractor. News of the young observer was spreading among professional astronomers, and shortly thereafter Princeton's **Henry N. Russell** loaned Peltier a 6-in. refractor, a comet seeker of short focus, through the AAVSO. In 1921, Peltier's father helped him build his first full observatory; it was ready for observing in January 1922.

Around 1937, the idea for the transportable, rotating observatory came to Peltier, perhaps due to his experience and expertise in furniture design. His idea was to be seated in a comfortable chair while observing variable stars or hunting for comets, and have the whole observatory revolve with the chair and telescope. Using both new and junkyard parts, Peltier built such an observatory. The chair included an adjustable headrest for comfort during long observing sessions, and a hot plate to warm his feet. Peltier's unique design later became famous as the "Merry-Go-Round observatory."

In 1959, the Miami University of Ohio donated a 12-in. Clark refractor, and a dome to contain the telescope. With the larger telescope, Peltier was equipped to observe much fainter stars and so he modified his observing program, concentrating on stars fainter than 11th magnitude. One important aspect of the new program was Peltier's observation of cataclysmic variable stars during their quiescent phase.

Peltier made independent discoveries of 12 comets, between 13 November 1925, and 26 June 1954; 10 of these comets bear his name. He carved the year of each comet discovery into the wooden tube of his 6-in. comet seeker. Peltier also made independent discoveries of six novae or recurring novae (Nova Aurigae 1918; Nova Cygni 1920; RS Ophiuchi 1933; DQ Herculis and CT Lacertae [both 1934]; and Nova Herculis 1963).

Except with his close friends, Peltier was a shy man and was uncomfortable with strangers. However, through the years Peltier met many prominent astronomers who came to visit him in Delphos, including **George van Biesbroeck**, **William Morgan**, **Bart** and Priscilla **Bok**, **Donald Menzel**, **Polydore Swings**, **John Hall**, **William Hiltner,** Clyde Fisher, and Walter Scott Houston. In 1932, Houston persuaded Peltier to travel with him to an AAVSO meeting in Cambridge, Massachusetts – a rare occurrence for Peltier who seldom left Delphos.

Peltier met Dottie Nihiser, daughter of a local beekeeper, in 1925. They shared many interests including geology and a love of nature. She attended Ohio Wesleyan University and had a great interest in archaeology. On the other hand, Peltier never finished high school. When his brother left for World War I, Leslie dropped out of high school and took over more farm chores, but his acquisition of knowledge never stopped. He married Dottie on 25 November 1933; she bore two sons, Stanley H. and Gordon J. Peltier. In 1934, Peltier left the farm to work at the Delphos Bending Company, designing children's toys and juvenile furniture. He was still employed by the company at the time of his death.

During the 1930s and 1940s, Peltier wrote articles on comet hunting, nature, and equipment design that appeared in magazines such as *The American Photographer*, *Popular Science*, *Nature Magazine*, and *Sky & Telescope*. He was the subject of articles in many popular newspapers and magazines. In 1965 Peltier's first book, *Starlight Nights, the Adventures of a Star-Gazer* was published. *Starlight Nights* is an autobiographical ode to the joys of observing both the night sky and nature. The language of the book is poetic, humorous, and beautifully descriptive in the style of a 19th-century naturalist. In 1972, Peltier published *Guideposts to the Stars: Exploring the Skies throughout the Year*. Departing from astronomy, in 1977 he published *The Place on Jennings Creek*, a natural history of their home, Brookhaven, and its surrounding areas.

Peltier was awarded a honorary D.Sc. degree by Bowling Green State University (Ohio) in July 1947. In August 1965, at the dedication of **Clinton Ford**'s observatory near Wrightwood, California, the mountain on which the observatory stood was christened Mount Peltier. Minor Planet (3850) was named Peltier in his honor in 1989. From 1925 to 1954 Peltier received the Astronomical Society of the Pacific's Donohoe medal for most of his comet discoveries. AAVSO honored Peltier with its First Merit Award in 1934, and with the Nova Award in 1963. Peltier also received the G. Bruce Blair Award from the Western Amateur Astronomers. After his death, the Astronomical League established the Leslie C. Peltier Award "for significant contributions to observational astronomy" and made the first award posthumously to Peltier himself.

Brenda G. Corbin

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Peregrinus de Maricourt, Petrus

Flourished **France, *circa* 1269**

Petrus Peregrinus is best known for his *Epistula de magnete*.

Of Peregrinus' life, almost nothing is known except what is revealed by his works and suggested by his name. Maricourt is almost certainly a reference to the village of Méharicourt in Picardy, and the appellation Peregrinus indicates that he was a crusader. But since his *Epistula de magnete* was written on 8 August 1269 from the siege of Lucera in Italy, the assault on which had been declared a crusade, it need not be assumed that he had visited the Holy Land.

Epistula de magnete is addressed to Peregrinus's dear friend Sigerus de Foucaucourt. Although not primarily an astronomical work, the text does describe two instruments with astronomical significance: an instrument incorporating a magnetic compass that could be used to determine the azimuth of celestial bodies and a magnetic clock, in the form of a lodestone terella (spherical magnet), which Petrus claimed would mimic the diurnal rotation of the heavens. This text was read by, and influenced, **William Gilbert**, and in the plagiarized form of the *De Natura Magnetis* (1562) of Jean Taisnier, it was studied by **Johannes Kepler** some years before Gilbert's own *De magnete* (1600) was published. It may, therefore, have contributed to Kepler's conceptualization of celestial forces.

Peregrinus also wrote, sometime after 1263, a *Nova Compositio Astrolabii Particularis*, a treatise on the construction of the astrolabe notable for its clarity, its comprehensiveness, and its unusual choice of projection. Petrus described both the standard stereographic projection from one pole and the universal projection of **Zarqālī** in which the West Hemisphere and East Hemisphere of the celestial sphere are projected onto a single plane, but opted for a projection in which the North Celestial Hemisphere and South Celestial Hemisphere were both projected onto the equatorial plane. However, this treatise does not seem to have been very popular; it survives in only four manuscripts, and does not appear to have been printed in the early modern period.

Adam Mosley

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Peregrinus, de Prussia

➔ **Pèlerin de Prusse**

Perepelkin, Yevgenij Yakovlevich

Born **Saint Petersburg, Russia, 4 March 1906**
Died **probably 1937**

Pulkovo Observatory's Yevgenij Perepelkin produced a nonhomogeneous model of the solar chromosphere in the 1930s. He was imprisoned and executed during a Stalin purge. Craters on both the Moon and Mars are named for him.

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Péridier, Julien Marie

Born **Sète, Hérault, France, 3 February 1882**
Died **Le Houga, Gers, France, 19 April 1967**

An electrical engineer by profession, Julien Péridier was an accomplished amateur astronomer who devoted the later years of his life to the development and operation of a substantial private observatory and scientific library. Péridier's early interest in astronomy can be traced to 1900 when he first observed variable stars. In 1933, Péridier established an observatory near the village of Le Houga in southwest France. It was equipped with a double 8-in. refractor with optics by André Joseph Alexandre Couder, a 12-in. Newtonian reflector that was made by George Calver, and a small transit telescope from Troughton & Simms. For nearly 30 years, Péridier observed actively from this station, while hosting young French astronomers who used his facilities for their own research as well as the observatory's programs. The main subjects of the research carried out at Le Houga were planetary physics, photometry, and stellar photometry, especially studies of variable stars and flare stars. There was also some work on double stars and galaxies. Péridier not only directed and sponsored this research but also published the results in the *Annales Astrophyśique* and also a score of *Publications de l'observatoire du Houga*, copies of which were exchanged with major observatories around the world. The Le Houga Observatory was selected by **Donald Menzel** as one of the sites from which Harvard College Observatory successfully observed the occultation of Regulus by Venus in July 1959. The last major project at the Le Houga Observatory was a 5-year National Aeronautics and Space Administration-sponsored program, conducted jointly with Harvard University from 1961 to 1965, involving multicolor photoelectric photometry of the Moon and planets with the 12-in. reflector.

Gérard de Vaucouleurs, who was both a collaborator at Le Houga from 1939 to 1949 and Péridier's longtime friend, likened him to the great private sponsors of American astronomical research including **Percival Lowell** and **Robert McMath,** as well as the great French amateur **René Jarry-Desloges**. This brief biography was extracted from an obituary prepared by de Vaucouleurs.

Thomas R. Williams

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Perrin, Jean-Baptiste

Born **Lille, Nord, France, 30 September 1870**
Died **New York, New York, USA, 17 April 1942**

French physico-chemist Jean Perrin was one of the early enthusiasts for nuclear (subatomic) energy sources for the Sun and stars, along the lines pursued more thoroughly by **Arthur Eddington**. He was the son of an army officer, who died soon after Jean's birth. He entered the Paris École Normale Supérieure in 1891, receiving his doctoral degree in 1897 for work on cathode rays and X-rays. Perrin showed that cathode rays are deflected in magnetic fields and so must carry negative charges, part of the evidence that led J. J. Thompson to the discovery of the electron.

Perrin began teaching at the University of Paris (Sorbonne) in 1897, and he was given a chair in physical chemistry there in 1910. Perrin remained at the Sorbonne until 1940, when he emigrated to the United States. Perrin was married in 1897 to Henriette Duportal; they had two children. Although he did not die in France, Perrin was eventually (1948) reburied in the Panthéon in Paris.

Perrin's work mainly focused on the nature of molecules. The atomic theory, which claimed that elements are made up of discrete particles called atoms and that chemical compounds are made up of molecules, was not fully appreciated at the end of the 19th century, and it had important opponents like Ernst Mach (1838–1916) and Wilhelm Ostwald. Robert Brown in 1827 had described the motion of very small particles, suspended in a fluid; in 1905 **Albert Einstein** gave some quantitative explanations for Brownian motion. Perrin studied colloidally suspended particles undergoing Brownian motion, and in 1908 started a series of experiments on this subject. Only then did he learn of Einstein's work, and finally – by using the "ultramicroscope" – he was able to confirm Einstein's predictions experimentally. Perrin was able to work out the size of the water molecule and a precise value for Avogadro's number. These results made clear that atomism was more than just a useful hypothesis. Already in 1913 Perrin had summed up the then known facts on molecules in his influential book *Les Atomes*. He was awarded the 1926 Nobel Prize in Physics.

During World War I, Perrin served in the Engineering Corps of the French army, working on remote acoustical detection of submarines and artillery fire, and inventing for the purpose a device called the telesite meter. In later years Perrin also became involved with institutional and organizational development of science in France. Thus in the late 1930s he was responsible for establishing both the Centre National de la Recherche Scientifique and the Palais de la Découverte in Paris at the 1937 International Exposition. He also was influential in the establishment of the Institut d'Astrophysique in Paris, and in the construction of the large Observatoire de Haute Provence. Perrin held honorary doctorates from several universities and in 1923 was elected a member of the French Academy of Sciences and served as its president in 1938.

Horst Kant

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Perrine, Charles Dillon

Born **Steubenville, Ohio, USA, 28 July 1867**
Died **Villa General Mitre, Argentina, 21 June 1951**

Charles Perrine, discoverer of Himalia (the sixth) and Elara (the seventh) satellites of Jupiter and nine new comets, began his astronomical career in the United States, but spent a large portion of it studying the Southern Hemisphere skies as director of the Argentine National Observatory at Córdoba, Argentina.

The son of Peter and Elizabeth Dillon (*née* McCauley) Perrine, Charles graduated from high school in Steubenville, Ohio, in 1884, and by 1886 had moved to San Francisco, California, where he worked as a business secretary until 1893. Interested in astronomy since high school, Perrine volunteered to observe the 1 January 1889 solar eclipse as part of an expedition organized by the Lick Observatory and became acquainted with **Edward Holden**. By 1893, Perrine had convinced Holden that he should be employed at Lick Observatory as the observatory secretary.

Perrine began his career in astronomy assisting Holden with nighttime celestial photography. By 1895, he had demonstrated sufficient aptitude that he was appointed assistant astronomer while continuing to serve as the observatory secretary. That same year, using the observatory's 12-in. Clark refractor, Perrine discovered the first of many comets credited to him. He was given full-time responsibility as an assistant astronomer 2 years later. As **James Keeler**'s assistant, Perrine continued to expand his observing repertoire, gaining skill on the Crossley 36-in. reflector as Keeler struggled to subdue the mechanical problems that plagued that instrument. After Keeler died and **William Campbell** was appointed to replace him, Campbell promoted Perrine to a full status as an astronomer. Mechanical upgrading of the Crossley reflector was incomplete at that time, so Campbell gave Perrine full responsibility for the instrument and its program. One of the many modifications Perrine made to the instrument was to place the photographic plate holder inside the tube at the primary focus, thus eliminating light loss from one reflection. Perrine's celestial photographs taken with the Crossley were excellent and in fact in some cases were substituted for photographs taken by Keeler before the instrument was fully functional in the *Keeler Memorial Volume* of the *Publications of the Lick Observatory*.

Perrine already had received five Astronomical Society of the Pacific's Donohoe Medals, each one for the discovery of "an unexpected" comet, when he was awarded the Paris Academy of Sciences' Lalande Prize and Gold Medal in 1897 for his comet discoveries. In total, between 1895 and 1902 Perrine discovered nine new comets and recovered four returning periodic comets. He made good use of the Crossley reflector for several other discoveries. Using the 36-in. telescope, he discovered the apparent superluminal motion of the expanding light bubble around Nova Persei (1901). Thought to be a nebula, the visual appearance was actually caused by the light from the nova event reflected from the surrounding interstellar medium as the light moved outward from the star. Perrine studied this phenomenon using photographic, spectroscopic, and polarization techniques. In 1904, he discovered Himalia, and found Elara in 1905.

Perrine had a deep interest in solar eclipses. Between 1900 and 1908, he led one Lick Observatory eclipse expedition to Sumatra (1901) and participated in several others. Campbell placed Perrine in charge of the Lick Observatory's observations of the 1901 opposition of the minor planet (433) Eros to measure the Earth–Sun distance. Perrine used Lick Observatory observations of Eros to publish an estimate of the solar parallax based on the Eros data in 1904.

Perrine left the Lick Observatory when he was appointed director of the Argentine National Observatory in Córdoba, Argentina, in 1909. He continued a program of modernization of Córdoba's facilities for conventional astrometry, the traditional program at Córdoba Observatory since it had been founded by **Benjamin Gould**. Equipment for the modernization had been ordered by Gould's successor, **John Thome**, who died before the Repsold meridian circle was completed in Hamburg, Germany. Perrine eventually completed the publication of all of the observatory's astrometric observations in 16 volumes of the *Resultados del Observatorio Nacional Argentino* along with an additional volume containing photographs from the 1910 return of Halley's comet (IP/Halley).

However, astrometry did not interest Perrine. His lasting contribution was the creation of the Astrophysical Station at Bosque Alegre (50 km southwest of Córdoba), which houses a 60-in. reflecting telescope. Almost from the day he arrived at Córdoba, Perrine was committed to establishing a leading position for Argentina in the emerging field of astrophysics. He persuaded the national government to fund the 60-in. telescope for which the mirror and mounting were to be produced in the shops at Córdoba. After upgrading the mechanical shops in anticipation of work on the 60-in. telescope, Perrine was successful in building a 30-in. reflecting telescope in the Córdoba shops and achieved noteworthy results with this instrument, the largest in the Southern Hemisphere. Unfortunately, he underestimated the difficulty of working the larger glass, and the project dragged on for many years. The delays in finishing the 60-in. mirror created a severe political problem for Perrine in the xenophobic atmosphere that dominated Argentina in the late 1920s and 1930s. He retired from the director's position of the Córdoba Observatory in 1936, but continued to live in South America until his death. Perrine was replaced by the Argentine astrophysicist Enrique Gaviola, who wisely arranged to have the large mirror finished by J. W. Fecker in the United States.

As a consequence of Perrine's farsightedness as the third director of the observatory, Córdoba became, for a time, the main astrophysical station in the Southern Hemisphere. Perrine wrote more than 200 papers between 1896 and 1947 on a variety of astronomical topics, including radial velocities of stars, comets, solar eclipses, the nature of globular clusters, nebulae, nova, and astronomical instrumentation.

In 1905, Perrine married Bell Smith of Philadelphia, Pennsylvania, USA. He was honored by Santa Clara College, California, in 1905 when that institution conferred an honorary D.Sc. upon him. Perrine was elected president of the Astronomical Society of the Pacific in 1902 and a foreign associate of the Royal Astronomical Society in 1904.

Scott W. Teare

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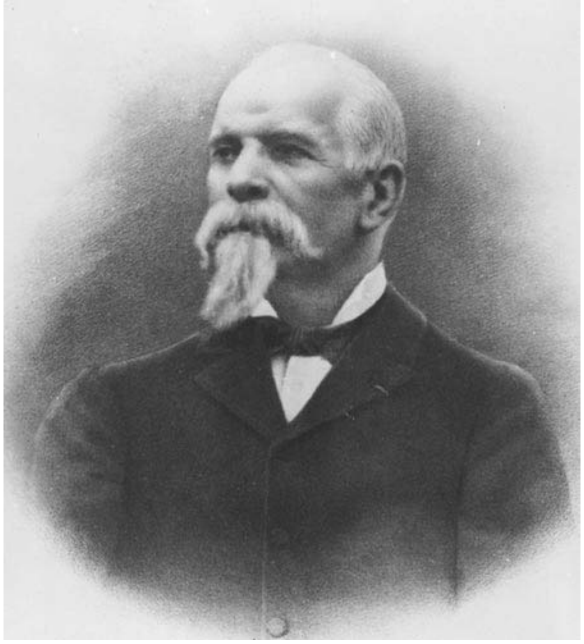
Perrotin, Henri-Joseph-Anastase

Born **Saint-Loup, Tarn-et-Garonne, France, 19 December 1845**
Died **Nice, Alpes–Maritimes, France, 29 February 1904**

Henri Perrotin achieved much of his recognition for his observations of planets and asteroids, as well as for his work in celestial mechanics on the determinations of their orbits. His astronomical observations were published in 50 notes in *Comptes rendus de l'Académie des sciences* from 1875 to 1903 and in *Astronomische Nachrichten* from 1875 to 1889.

Perrotin was born into a family of modest means in the southwest of France, and received scholarships for his education at the lycée in Pau. He began his astronomical career with **Félix Tisserand**, a professor of celestial mechanics at the Faculté des Sciences of Toulouse. When Tisserand became director of the Toulouse Observatory in 1873, he appointed Perrotin as astronomer. The year after, the novice astronomer discovered his first asteroid, which he called (138) Tolosa. Perrotin discovered five more, the last one in 1885.



Following the method used by **Urbain Le Verrier** for the big planets, particularly Jupiter and Saturn, Perrotin started to develop the first precise orbital theory of the minor planet (4) Vesta, the topic of his thesis in 1879. In this work, he used a perturbation function of the eighth order in the eccentricities and inclinations, an achievement that has been applied by astronomers to verify recent theories of Vesta.

In 1880, Perrotin was directed by the Bureau des longitudes to banker Raphaël Bishoffsheim to install the private observatory that Bischoffsheim was founding in Nice on Mont Gros. After visiting the most important observatories in Europe to study their organization and development, Perrotin supervised the installation on Mont Gros the next year. As its first director, a position he held for more than 20 years until his death, he devoted himself to setting up a well-equipped observatory, and to supervise its growth. His work and research there related to astrometry (of asteroids, comets, double stars, and satellites), astrophysics (pertaining to the study of planetary surfaces and the velocity of light), and celestial mechanics (orbits of asteroids and planets).

In 1882, the Académie des sciences designated Perrotin as the leader of the expedition to observe the transit of Venus in Patagonia, at Carmen de Patagonès (Argentina) on the banks of the Rio Négro. His return to Nice marked the beginning of the most active part of Perrotin's career. He provided the impetus for a variety of work concerning the construction of instruments and scientific research. Perrotin greatly contributed to the renown of the observatory, supervising the installation of many instruments, including the 30-in. refractor (1886), one of the world's largest at the time. He used it to carry out observations of double stars, and of large and small planets.

Perrotin tried to verify two findings of **Giovanni Schiaparelli**: his discovery of the so called canals of Mars and his determination of Venus's rotational period as 225 days. On both counts, Perrotin confirmed the Milan astronomer's results, though later findings disproved the former and showed the inaccuracy of the latter. Yet his own detailed observations of the Martian surface proved of great interest, and his drawings of Venus's surface (1890) show that 70 years before their widespread recognition, he had visually noticed the now famous Y- and Ψ-shaped markings recognized today in the Venusian clouds.

Perrotin also organized meteorological and magnetic observations, and contributed to physics by determining the velocity of light. He made a series of accurate observations using the slotted-wheel technique developed by **Armand-Louis Fizeau**, and applied it to beams sent between Mont Gros and Mont Vinaigre, the highest point of the massif of Estérel 46 km away. The 299,880 km/s value obtained in 1902 was regarded as the best until the measurements taken by **Albert Michelson** in 1926.

Perrotin founded the *Annales de l'Observatoire de Nice* in 1887. He managed the publication of the first ten volumes, and wrote several of them. He was twice awarded the Lalande Prize by the Académie des sciences (1875 and 1884), and was a corresponding member of the Académie des sciences (1892) and of the Bureau des longitudes (1894).

Raymonde Barthalot

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Peters, Christian August Friedrich

Born **Hamburg, (Germany), 7 September 1806**
Died **Kiel, Germany, 8 May 1880**

During the second third of the 19th century, a time of widespread emphasis on astrometrical precision, Christian Peters studied from and worked with the first two observers of stellar parallax and deduced the orbit of an unseen companion of the star Sirius. Born in a family of merchants, Peters displayed a precocious ability in the mathematical sciences. He received encouragement from **Christian Schumacher**, the genial founder and first editor of the leading astronomical scholarly journal, *Astronomische Nachrichten*. Peters's first astronomical publications, completed before he was 20, appeared in that journal in 1826.

On matriculating at the University of Königsberg in East Prussia (presently Russia) and studying under **Friedrich Bessel**, Peters joined the leading exponent of the scientific value of precision measurement. Peters's scientific career developed in the direction suggested by Bessel, who advocated the application of advanced mathematical techniques to improve precision by paying close attention to the analysis of both stochastic and systematic errors. Bessel's first extended application of careful error analysis involved the seconds pendulum; Peters's 1834 Ph.D. dissertation discussed the effect of air resistance on the pendulum. Bessel successfully applied his techniques to the centuries-old search for stellar parallax in 1838, inspired by the preliminary announcement by **Friedrich Struve** in 1836 of a parallax for the star Vega. Peters, who worked from 1839 untill 1849 under Struve's direction at the Pulkovo Observatory, some 400 miles up the Baltic Sea coast from Königsberg, made the critical comparison of the emerging measures of stellar parallax his specialty.

Peters worked productively as one of Struve's four assistants, publishing in 1842 his determination of the motion of the pole star and the constant of nutation. He became an adjunct (1842) and then an extraordinary (1847) member of the Saint Petersburg Academy of Sciences. In 1852, Peters won the Royal Astronomical Society of London Gold Medal for his work at Pulkovo Observatory. He also engaged in a polemical exchange with **Johann von Mädler**, Struve's successor at the University of Dorpat observatory.

In 1844, Bessel announced that irregularities he detected in the proper motions of Sirius and Procyon implied that these stars were orbited by unseen companions. After Bessel's death in 1846, August Ludwig Busch, Bessel's successor at Königsberg, made it possible for Peters to return as full professor of astronomy. In 1851, Peters produced a 60-page paper calculating the orbit of the companion of Sirius, despite Struve's doubts about its existence. While testing what was then the world's largest objective lens, United States telescope-maker **Alvan Clark** observed the predicted companion for the first time in 1862.

In 1854, Peters accepted the prestigious directorship of the Altona Observatory, in a suburb of Hamburg, and with this position also the editorship of the *Astronomische Nachrichten*. While at the professional summit of the German-speaking astronomical community for the next quarter of a century, Peters published a more technical journal (that appeared more frequently) than before, but he was opposed by astronomers working within the Russian empire. The practice of separate publication of the most important results from Pulkovo in the *Astronomische Nachrichten* came to an abrupt end as soon as Peters became editor. German astronomers complained of a greater degree of partisanship in the journal, and its circulation suffered.

After Germany was unified in 1870, the imperial authorities agreed to Peters's 1864 suggestion to move the instruments of the Altona Observatory 50 miles to Kiel and build a larger observatory for the university there. Peters served as professor of astronomy at Kiel from 1874 until his death.

Michael Meo

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Winnecke, [Friedrich August Theodor] (1881). "Nekrolog." *Vierteljahrsschrift der Astronomischen Gesellschaft* 16: 5–8. (States that Peters took the editorship of the *Astronomische Nachrichten* over the opposition of "the leading Russian astronomers," which phrase likely refers to Otto Wilhelm Struve, director of Pulkovo at the time.)

Peters, Christian Heinrich Friedrich

Born **Coldenbüttel, (Schleswig-Holstein, Germany), 19 September 1813**
Died **Clinton, New York, USA, 18 July 1890**

Christian Peters, who played a subsidiary role in the rise of the American astronomical community to international prominence, was one of several senior scientists who emigrated from Europe to the United States prior to the American Civil War.

Peters received a classical education at the Gymnasium in Flensburg, Germany, obtained a Ph.D. from the University of Berlin in 1836 in theoretical physics, and continued his studies under **Carl Gauss** at the Göttingen Observatory, after which he devoted himself to positional astronomy. Under Gauss's influence, German astronomers of the 1830s engaged in a substantial program of geodetic mapping. Peters worked on a survey of Mount Etna in Sicily from 1838 until 1843, and was then promoted to director of the government trigonometric survey of Sicily. When in 1848 that island was swept by an antimonarchial revolution, one of a dozen or so that year throughout Europe, Peters supported the revolutionaries. He left for neutral Turkey when the monarchial troops invaded and reestablished the royal government.

During 5 years in Constantinople with few prospects for scholarly work, Peters managed to learn Arabic and Turkish. He then joined the group of skilled scientists going to the United States. In 1854, at the urging of the American ambassador to Turkey, he emigrated to Massachusetts, where **Benjamin Gould**, who had known him in Göttingen, helped him get a position in the United States Coast and Geodetic Survey, working under Gould's supervision. Peters arrived in his new country the same year as **Franz Brünnow** came from the University of Berlin Observatory to head the new observatory at the University of Michigan.

Mercantile philanthropists in Albany, New York, had subscribed generously to the establishment of a research-grade astronomical observatory, the first American observatory devoted solely to research, and invited Gould to be director; he agreed to act as a scientific consultant during construction. Although there is little doubt that the head of the Coast Survey, **Alexander Bache**, would have allowed Gould to be present during construction, he preferred to remain in Cambridge, Massachusetts, and to send Peters to Albany. The contrast between the diffident and competent Peters and the nervous and abrasive Gould so struck the businesslike trustees that they invited Peters, who resigned from the Coast Survey, to step in as director of what was to be called the Dudley Observatory. Gould, Bache, and the head of the Smithsonian Institution, **Joseph Henry**, interpreted Peters's acceptance of the position as betrayal, and by personal intervention and material inducements persuaded the trustees to release Peters, who was then shunted to the directorship of the Hamilton College Observatory in Clinton, New York.

As director there from 1858 to 1890 under difficult circumstances, Peters conducted a program of precision positional astronomy to the standards of accuracy demanded by contemporary research. The 13.5-in. refractor on an equatorial mount at Hamilton was the largest American-made refractor in the United States when Peters arrived. Its quality had convinced Gould to engage its maker, Charles A. Spencer of Canastota, New York, to build the main research instrument of the Dudley. Noting the acclaim afforded Brünnow's discovery of several new asteroids, Peters undertook the colossal project of mapping all stars, down to 14th magnitude, within a zone of 30° on either side of the ecliptic, during which effort he discovered at least 42 new asteroids of his own. Most of his results appeared in the *Astronomische Nachrichten*, the leading scholarly astronomical journal of the day, although he made use of the *Astronomical Notices* as well, founded and edited by Brünnow while he was in the United States (1858–1862).

Two problems frustrated Peters's ambitious research program. The first was inadequacy of means. He wrote several times to his close friend **George Bond**, director at the Harvard Observatory, lamenting his arrears in pay; on 1 February 1863, he mentioned consulting a lawyer about obtaining the previous year's salary. Fortuitously, in 1867, the owner of a railroad living in nearby Delphi Falls donated enough money to Hamilton to endow its astronomer with a modest salary; the Litchfield professor of astronomy from then on directed the now-renamed Litchfield Observatory. Peters's plan of work envisioned 182 charts of carefully determined star positions, but only 20 were ever published.

A second development doomed Peters's plan: instrumental change. The 1870s and 1880s saw the increasing use of photography in positional astronomy – Peters himself was one of three American representatives participating in the International Astrophotographic Congress held in Paris in 1887 – but all work at Hamilton College was visual. Even so, the quality of his work elevated Peters to the elite National Academy of Sciences in 1876, the Royal Astronomical Society of London in 1879, and the French Legion of Honor in

1889. He was selected as chief of the 1874 American transit of Venus expedition sent to New Zealand.

The Coast and Geodetic Survey, the United States Naval Observatory, the Nautical Almanac, and the Harvard College Observatory were the leaders in the emerging American participation in contemporary astronomical research in the second half of the 19th century. The careful, numerous, and hard-won contributions of Christian Peters to positional astronomy were a minor but helpful part of that process.

Michael Meo

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Bruce, Robert V. (1987). *The Launching of Modern American Science, 1846–1876*. New York, Alfred A. Knopf, pp. 237ff. (Bruce points out that Peters's career at Hamilton College, far from the "empty dazzle" that Gould and his backers lamented, was devoted to just the compilation of star catalogs and positional computations for which Gould had intended his never-acquired heliometer.)

Dick, Steven J., Wayne Orchiston, and Tom Love (1998). "Simon Newcomb, William Harkness and the Nineteenth-century American Transit of Venus Expeditions." *Journal for the History of Astronomy* 29: 221–255. (See pp. 224–232 for details of Peters's leadership of the 1874 American expedition to New Zealand to observe the transit of Venus.)

James, Mary Ann (1987). *Elites in Conflict. The Antebellum Clash over the Dudley Observatory*. New Brunswick, New Jersey: Rutgers University Press. (See especially, Chap. 6: "Conflict Begins: The Peters Problem." In discussing in detail the struggle over the direction of the Dudley Observatory, James uses "manic-depressive" in describing Gould, and "calculating" for Peters.)

Jones, Bessie Zaban and Lyle Gifford Boyd (1971). *The Harvard College Observatory: The First Four Directorships, 1839–1919*. Cambridge, Massachusetts: Harvard University Press. (See p. 122 for Peters's financial concerns.)

Lankford, John (1997). *American Astronomy. Community, Careers, and Power, 1859–1940*. Chicago: University of Chicago Press. pp. 165ff. (He characterizes Peters's work as a "failed career," since "the application of photography to astronomy … rendered visual mapping of the sky obsolete." Further, according to Lankford, Peters was "demanding, indeed dictatorial, in the fashion of a European institute director.")

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Peter of Ailli

➔ **D'Ailly, Pierre**

Petit, Pierre

Born	**Montluçon, (Allier), France, 8 December 1594 (?) or 31 December 1598**
Died	**Lagny-sur-Marne, (Seine-et-Marne), France, 20 August 1677**

Physicist, mathematician, astronomer, and instrument maker Pierre Petit was christened on 31 December 1598. He was one of seven children born to Pierre Petit, then *contrôleur en l'élection* in Montluçon, a town situated in the Bourbonnais region of France, and Marie (*née* Bonnelat) Petit. As a young man, Petit assumed the duties of his father's office in 1626. But being more interested in scientific matters, he gave up this position and went to Paris in 1633. During his lifetime, Petit served in many official capacities, as a *commissaire provincial d'artillerie*, as an engineer and geographer to King Louis XIV, and as *intendant général des fortifications* in France.

While at Paris, Petit became a friend of **Marin Mersenne**, and was included in meetings of Mersenne's circle. Petit also became acquainted with Etienne Pascal and his mathematician son, Blaise Pascal. It was from Mersenne that Petit learned about **Evangelista Torricelli**'s experiments with the barometric vacuum and, helped by the Pascals, he successfully repeated them. Following Mersenne's death, this group met at the residence of Henri-Louis Habert de Montmor, and became known as the Académie de Montmor. There, Petit was introduced to **Adrien Auzout**, **Jean Picard**, and **Christiaan Huygens**. In conjunction with Auzout and Picard, Petit helped to perfect an instrument known as a filar micrometer, used to measure the very small angles of celestial objects viewed through a telescope. Petit also produced the earliest surviving sketch (1662) of the "magic lantern," or lantern projector, in his correspondence with Huygens.

By 1664, however, the Académie de Montmor had exhausted its funds. An appeal for assistance was directed to Jean-Baptiste Colbert, French statesman and financier. Two years later, King Louis XIV established the Académie royale des sciences, following many of the suggestions proposed by the academicians. Petit, however, was not among the founding members of the Académie des sciences, perhaps because he held a full-time government position. In 1667, however, Petit was named a corresponding member of the Royal Society of London.

Petit's most important astronomical work was his *Dissertation sur la nature des comètes* (1665). Therein, he speculated that a bright comet seen in December 1664 was the same as another viewed in 1618. Petit surmised that the comet had an elliptical orbit with a period of 46 years. He even went so far as to predict the return of this comet in 1710. Petit, however, was wrong about the particulars of this assertion. (Comets C/1664 W1 and C/1618 W1 were neither identical nor periodic). Yet his suggestion that comets might be periodic phenomena helped to diminish lingering fears and superstitions about their mysterious nature.

Petit also published a study on magnetic declination. His astronomical equipment included graphometers, quadrants, and objective lenses fashioned by the optician **Giuseppe Campani**. Petit married and had, among his children, one daughter, "Marianne", who became a *bénédictine* at Lagny-sur-Marne. A street and place, situated in the old part of Montluçon, bear Petit's name.

Suzanne Débarbat

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Petrus Apianus

➔ **Apian, Peter**

Petrus Dacus [Danus]

➔ **Nightingale, Peter**

Petrus de Alliaco

➔ **D'Ailly, Pierre**

Petrus [Philomena] de Dacia

➔ **Nightingale, Peter**

Pettit, Edison

Born **Peru, Nebraska, USA, 22 Sept 1889**
Died **Tucson, Arizona, USA, 6 May 1962**

Edison Pettit, American astronomer best known for accurate measurements of the color temperatures of planets and stars, was the son of George Knox Pettit and Martha Ann Knox. He married Elizabeth Schmauser and, later Hannah Bard Steele. Their children were Helen Bard Pettit Knaflich and Marjorie Steele Pettit Meinel.

Edison Pettit was given no middle name because his parents thought "Edison" was a unique first name. (He was born at the time of Thomas Edison's inventions relating to electrical power.) George Pettit owned a sawmill and converted its machinery from steam-belt drive to steam-generated electricity drive. Young Edison Pettit, in fact, earned money for his education by helping to his father's growing electrical power plant wire up the village.

Pettit received his B.Ed. from Nebraska Normal College, Peru, Nebraska, in 1911. Following this he taught, first, science at Minden (Nebraska) High School, and then physics and astronomy at Washburn College, Topeka, Kansas, before going on to Yerkes Observatory to work on a Ph.D.

Pettit was a Ph.D. student at Yerkes when the army drafted him into World War I. At the Induction Center, when the soldiers manning the induction desk saw he gave "astronomer" as his job on his papers, they commented, "Of what use is an astronomer ? " Fortunately, the officer in charge recognized Pettit's worth and assigned him to the United States Army Signal Corps. There Pettit worked with the optical scientist, **Robert Wood** at Johns Hopkins University. He was given the task of measuring the optical properties of materials and of assisting Wood in experiments with gas-filled balloons used as reconnaissance platforms. On the first flight, they nearly brought down the municipal gas supply of Baltimore.

Following the war, Pettit finished his Ph.D. at Yerkes Observatory where he had met his second wife, Hannah, the first woman to earn a Yerkes/University of Chicago Ph.D. in astronomy (guided by **Edwin Frost,** then director). They both extensively used the Yerkes 40-in. telescope. One night, while he was rewinding the drive weights, Edison's necktie got caught in the telescope drive mechanism and threatened to slowly strangle him. From the library, Hannah heard him cry out. She got scissors, ran to the dome, and severed his necktie. After that Edison never wore a necktie, only a black bow tie. Edison Pettit received his Ph.D. in 1920 for studies in solar physics, especially the spectra of prominences. Hannah's was for astrometric work. In 1920, shortly after establishing a solar observatory on Mount Wilson in California, **George Hale** asked Edison to join him on the staff of Mount Wilson Observatory [MWO]. Pettit accepted, and asked if there also was a position available on the staff for Dr. Hannah Pettit. Hale replied that it was not possible for women to be on the staff: only men. This remained true for five decades. Much of Edison Pettit's MWO work was done with the 60-ft. solar tower, to be followed in a few years by the 150-ft. tower.

In the winter of 1925–1926, the Pettit family went to the University of Arizona, Tucson, where Edison did research at the Tucson Tuberculosis Sanitarium (now the Tucson Medical Center) on ultraviolet transmission of glasses and the possible beneficial effect of solar ultraviolet radiation on tuberculosis patients. (His first wife, Elizabeth, had died of tuberculosis.) In 1930, he again took his family to Tucson where he assisted **Andrew Douglass** in upgrading the 36-in. telescope of the university's Steward Observatory, at that time located on the campus.

In addition to his solar work, Pettit had a laboratory at the MWO Pasadena offices to support his developments in radiation measurements of astronomical sources. In the 1920s, he built an ultrasensitive thermocouple and, with **Seth Nicholson**, made the first measurements of the temperature of the Moon, both the solar-illuminated and night surfaces, which showed the fine granular nature of the lunar surface.

Pettit and Nicholson extended temperature measurement to Venus, Mars, Jupiter, and Saturn, using the MWO 100-in. telescope. The values they obtained were confirmed in the 1970s when spacecraft first visited these planets. In 1944, Pettit was asked to use his expertise to build three thermocouples and to hand-deliver them to Alamogordo, New Mexico, where they were used to monitor the output of the first nuclear explosion.

During the summers of 1930–1936, Pettit took his family to Yerkes Observatory and made solar prominence observations using Hale's spectroheliograph on the 40-in. refractor. Pettit's attention was focused on why eruptive prominences show several sudden jumps in their upward motion before blasting into space. To follow this up he went to Michigan in the summers of 1936–1938 to test and then to use the new spectroheliokinematograph at the McMath–Hulbert Observatory.

In 1939, Pettit built a home observatory equipped with an Alvan Clark 6-in. refractor. For years this old telescope had lain in a barn, covered with trash, on a farm in Michigan. It now had been offered for sale. The owner would not let a buyer inspect it, but Pettit could see that although the telescope had been neglected, it was at least intact. After the owner accepted his fair price offer, another astronomer slyly told her that Pettit had offered too little, so she raised the price.

Nonetheless, Pettit took the 6-in. home to Pasadena and refurbished it so that it looked and worked like new. Now he could do much more of his observing from his home rather than on Mount Wilson, an advantage since his wife Hannah was a semi-invalid.

Shortly after **Yngve Ohman** invented the quartz-polarizing monochromator, Pettit designed and built one in his small home machine shop, adding a time-lapse movie camera. Attaching this at the eyepiece of his telescope made possible photographing solar prominences from the convenience of home. Assisted by Marjorie, he obtained enough movies of eruptions to enable him to refine a set of "laws" describing the motion of eruptive prominences. Understanding why they erupt in this manner required the discovery of magnetohydrodynamics and model of solar flares; subtleties in their behavior still puzzle solar theorists.

The Clark refractor saw additional duty as Pettit frequently had groups of amateur astronomers and the public come to look through the 6-in. at the planets, especially during the excellent 1940 opposition of Mars. That telescope and monochromator are still in use, but now in a small observatory in Prescott, Arizona.

A backyard telescope has other advantages. One winter morning in 1941, Pettit went out before dawn to pick up the morning newspaper. He was startled to see a new bright star shining low in the south. He immediately ran to the backyard, opened the sliding roof, and turned the telescope on the new star – Nova Puppis. Reading off its coordinates and measuring its magnitude, he sent a telegram to Harvard College Observatory with the news. However, Pettit was about 2 hours too late to be the discoverer of a nova, since a telegram had just been received from South America where it had been discovered first.

As photoelectric observations took center stage for precision brightness measurements, Pettit's interests moved from solar and planetary observations to measuring the radial brightness distributions of over 500 galaxies. During his retirement years, he used his home machine shop to build spectrographs and small instruments for a number of observatories and universities. Following the death of Hannah, and a subsequent stroke, Edison moved to Tucson to live with Marjorie Meinel and her family.

Pettit received a honorary degree from Carthage College (LL.D.) in 1935, and craters both on the farside of the Moon and on Mars are named for him.

Marjorie Steele Meinel

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Peucer, Caspar

Born **Bautzen, (Sachsen, Germany), 1 June 1525**
Died **Dessau, (Sachsen-Anhalt, Germany), 25 September 1602**

In his textbooks Caspar Peucer argued for the importance of studying astronomy; he also wrote on the new star of 1572, and defended certain aspects of astrology.

Peucer was the child of Gregor Beucker, a *Bürger* of Bautzen, and Ottilie Simon. He was educated at the University of Wittenberg, matriculating there in March 1543, and graduating MA in September 1545. He went on to distinguish himself as a professor at Wittenberg, first in lower mathematics (1550), then higher mathematics (1554), and finally, after graduating as a doctor of medicine in 1560, in the medical faculty. His first wife, Magdalena, was the daughter of Philipp Melanchthon; she bore him three sons and seven daughters, but died in 1575. Between 1576 and 1586, Peucer was imprisoned as a crypto-Calvinist by August von Saxony, whom he had previously served as counselor and physician. His release was effected through the petition of Joachim Ernst von Anhalt, whom he then likewise served in both of these capacities. In 1587 Peucer married Christine Schild, a widow of Bautzen; this second marriage was without any issue.

Peucer's significance to astronomy lies partly in his authorship of astronomical texts, and also in the position he held within the astronomical community of the later 16th century. Peucer's professors at Wittenberg had included Melanchthon, **Rheticus**, and **Erasmus Reinhold**, and as a professor of higher mathematics (astronomy) in his own right, and an author of textbooks that had their origin in his lectures, Peucer played a large part in propagating both the Philippist view of the importance of astronomy within the arts curriculum and the so called Wittenberg interpretation of the Copernican world system. Peucer's pupils included Johannes Praetorius, Victorin Schönfeld (who became professor of mathematics at Marburg), and Jørgen Dybvad (later professor of theology, natural philosophy, and mathematics at Copenhagen). In addition, he was consulted by princes, including Landgrave **Wilhelm IV** of Hessen-Kassel, about such phenomena as the supernova of 1572 (SN B Cas), and he included among his correspondents the Danish astronomer **Tycho Brahe**. Peucer's standing within the astronomical community is suggested by the fact that Brahe attempted to use Peucer as the arbiter of his disputes with **Christoph Rothmann**, and addressed to him an important epistolary defense of his claim to priority in the development of the geoheliocentric world system.

The most astronomically significant of Peucer's own works are the *Elementa doctrinae de circulis coelestibus*, first published in 1551, and the *Hypotheses astronomicae*, first published under his name in 1571, after a previous version had been published in 1568 without his consent. His treatise on the new star of 1572 was published at Wittenberg, and later reproduced by Brahe. Peucer's *De dimensione Terrae* of 1550 was essentially a geography textbook, but one heavily indebted to the techniques of spherical astronomy. His *Commentarius de praecipuis divinationum generibus* of 1553 is worthy of mention since it included a section on astrology, the practice of which provided one of the chief motivations for astronomical study in the early modern period; in defending the legitimacy of certain forms of astrological divination Peucer was again following the lead of his father-in-law Melanchthon.

Adam Mosley

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Peurbach [Peuerbach, Purbach], Georg von

Born **Peurbach near Linz, (Austria), possibly 30 May 1423**
Died **Vienna, (Austria), 8 April 1461**

Georg von Peurbach continued a strong tradition in which the University of Vienna was considered to have the best astronomy scholars in Europe during the 15th and early 16th centuries.

Peurbach was born sometime after 1421, the date of 30 May 1423 coming from a horoscope published as late as 1550. Peurbach received a bachelor's degree in 1448 and his master's degree 5 years later, both at the University of Vienna. As a lecturer at the university there, he was one of the leaders in reviving classical Greek and Roman literature in the arts and sciences. After observing an occultation of Jupiter by the Moon in 1451, Peurbach spent the last decade of his life making observing instruments, lecturing on astronomy and the classics, collaborating with men such as **Johann Müller** (Regiomontanus) on astronomical observing and theory, and serving as imperial astrologer to the king of Hungary. Peurbach died of unknown causes.

Peurbach evidently made many astronomical observations during the last 10 years of his life with his famous student Regiomontanus, including taking measurements of lunar eclipses during 1457–1460 whereby the two astronomers carefully noted observing location and times, altitudes of the Moon and various stars, and degree to which the Moon was seen inside the Earth's umbral shadow. Such observational detail was not only highly unusual for medieval observations, but it also helped to set a precedent for 16th-century observers who tried to emulate the work of the Vienna astronomers. Peurbach observed Halley's comet (IP/Halley) in 1456, using instruments to record the ecliptic positions of the comet's head and tail on two nights and to make some assessment of the comet's distance from parallax measures. That a comet's position would be measured as seriously as a planet's indicated the beginning of moving away from **Aristotle**'s claim that comets were merely atmospheric phenomena; this was also apparently the first attempt to seriously determine a comet's distance from parallax, a procedure elaborated upon by Regiomontanus and widely discussed and refined in the 16th and 17th century by others.

Led by Peurbach and Regiomontanus, the Vienna group sought actively to reform astronomy by improving on theory through the beginning of systematic observation of the planets, Sun, Moon, and stars. Peurbach's *Nouae theoricae planetarum* (New theories of the planets), which involved revised theories of the Ptolemaic system (evidently augmented by the ideas of Arabic astronomers), was published posthumously in numerous editions from 1472 to 1596, edited by such notable scholars as Regiomontanus, **Peter Apian**, **Erasmus Reinhold**, and Philip Melanchthon. No less than 56 printings of this Latin text appear to have been made up to 1653, with additional printings in other languages. (While still working toward his master's degree, Regiomontanus apparently heard Peurbach's lectures on this text in 1454 at Vienna.)

Peurbach also prepared and issued tables predicting eclipses of the Sun and Moon (a practice continued by Regiomontanus), and

Peurbach seems also to have supervised the collecting and copying of astronomical manuscripts, leading evidently to the establishment of the scientific printing press by Regiomontanus to publish astronomical tracts (including Peurbach's *Nouae theoricae planetarum* and the ancient poet **Manilius**'s *Astronomicon*).

At the request of Cardinal Bessarion, Peurbach began in 1460 a translation, with commentary, of **Ptolemy**'s *Almagest*; this was cut short by Peurbach's death, but was continued to completion by Regiomontanus and eventually published under the title *Epitome of the Almagest* in 1496. The *Epitome* was an important reference in the following decades for **Nicolaus Copernicus** during his preparation of *De Revolutionibus*. Peurbach also influenced Regiomontanus for the development of advanced trigonometric relationships that would be used by astronomers in the century to come.

Peurbach's *Theoricae novae planetarum* was published by Regiomontanus from his printing press in Nuremberg. Though many Peurbach manuscripts seem to have circulated (particularly on astronomical theory and practice, including instrumentation), other work by Peurbach was even more delayed in terms of printing, his observations not being fully published until nearly a century after his death by **Johann Schöner**.

Daniel W. E. Green

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Pfund, August Hermann

Born **Madison, Wisconsin, USA, 28 December 1875**
Died **Baltimore, Maryland, USA, 4 January 1949**

American spectroscopist and colorimetrist August Pfund received a BS from the University of Wisconsin in 1901 and a Ph.D. from Johns Hopkins University, Baltimore in 1906. He held research positions from 1906 to 1910, an associate professorship (1910–1927), and a professorship at John Hopkins University from 1927 until his retirement. Pfund appears occasionally in astronomy books because of his discovery of the fifth series of hydrogen lines, that is, those arising from the $n = 5$ electron shell, the third in the infrared after the Paschen and Brackett series. Pfund lines have wavelengths longer than 2.28 μm. There is no limit to such series, and transitions from $n = 108$ and 109 can be studied at radio wavelengths.

Pfund received medals from the Franklin Institute and the Optical Society of America.

Virginia Trimble

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Phillip of Opus

Flourished **(Greece), fourth century BCE**

Ancient sources attribute a number of astronomical "firsts" to Phillip. However, these sources date from centuries after Phillip's time.

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Phillips, Theodore Evelyn Reece

Born **Kibworth, Leicestershire, England, 28 March 1868**
Died **Walton-on-the-Hill near Headley, Surrey, England, 13 May 1942**

Reverend Theodore Phillips led the British Astronomical Association [BAA]'s Jupiter Section for 31 years. In the process, from both his own outstanding observations and those of other observers, Phillips compiled an unprecedented continuous record of the visual surface features of Jupiter, a record that for the most part cannot be duplicated from any other source. His analysis of the currents in various zones and belts of Jupiter is a model for all such efforts.

The son of an Anglican minister, Reverend Abel Phillips, Theodore matriculated at Oxford, where he graduated with a BA degree from Saint Edmund's Hall, Oxford, England, in 1891 and earned a MA at Oxford University in 1894. Ordained as a minister in the Church of England in 1891, Phillips served as the curate of the parish of the Holy Trinity at Taunton, and then was appointed to a similar role at Hendford, Yeoville, in 1895.

It was around 1895 that a parishioner, aware of Phillips's interest in science, made a gift of a 3-in. Grubb refractor to Phillips. When Phillips chanced upon Saturn during his first observing with this telescope, the beauty of the object created an enthusiasm for astronomy that would influence him for the rest of his life. In 1896 Phillips joined the BAA and began systematically observing Jupiter and Mars with a 9¼–in. reflector on an alt-azimuth mount. With respect to Jupiter, Phillips soon recognized the importance of the pioneering work of **Arthur Williams**, which had in the main been largely ignored by the directors of the Jupiter Section. Soon after Phillips joined the section in 1896, the apparition memoirs began to reflect this new awareness. In 1901 Phillips was appointed director of the BAA Jupiter Section. He changed little at first, but by 1914 had completely revised the reporting process for Jupiter. Instead of preparing drift charts for each individual observer, the practice that emerged from his initial emphasis on the work of Williams, Phillips consolidated the results of all observers for each zone or belt, in the process not only simplifying the reporting but also making the analysis much more rigorous and likely more accurate. Takeshi Sato, a planetary observer, called Phillips the "Father of the Jupiter Observation." William Edwin Fox (1898–1988), a later BAA Jupiter Section director, characterized Phillips by stating "as a planetary draughtsman, he was unsurpassed."

Phillips sustained his energetic role in astronomy in spite of increasingly demanding professional assignments. In 1901, the same year he successfully assumed responsibility for the Jupiter Section, he was reassigned to a curacy in the parish of Saint Saviour, Croyden, followed by another assignment as curate in Ashstead, Surrey. While assigned at Croyden, Phillips met and married Millicent Kynaston; they had one son.

Phillips's involvement in astronomy continued to grow during this period. Having been elected a fellow of the Royal Astronomical Society [RAS] in 1899, Phillips was elected to the RAS Council in 1911. He served nearly continuously in that body until his death, including terms as secretary (1919–1925) and president (1927–1929). Phillips is one of only two amateur astronomers to serve as the RAS president after 1907, the other being **William Steavenson**.

Reverend Phillips assumed even greater church responsibility when, in 1916, he became the rector of Headley. This was, however, seen as a longer-term assignment, so he built an observatory near the rectory that eventually housed two telescopes, an 8-in. Cook refractor, and a 12-in. Calver equatorial reflector that was later replaced by an 18-in. With reflector. Phillips observed double stars with the refractor but employed the reflectors for his planetary studies. Phillips was fond of using the filar micrometer, which had reached its engineering peak in the 19th century, and contributed a long series of double star measures in annual reports to the *Monthly Notices of the Royal Astronomical Soceity*.

Phillips's planetary observing was not limited to Jupiter. For a time Phillips was known as one of the world's more prolific Mars' canalists along with BAA observers **Percy Molesworth** and **Eugéne Antoniadi**. When he observed Mars for the first time (with the 9¼-in. reflector), Phillips is reported to have declared "My experience of Martian observation this winter has led me to believe that Mars is not nearly so difficult an object as is commonly supposed, and that many of the canals are easy." Phillips observed at every opportunity during 43 oppositions of Mars. His drawings, which eventually displayed no canals, reflect the care and skill he evidenced in his Jupiter observations.

Phillips was known as an inspiring person and a gifted speaker. It would have been interesting to listen to a sermon on the heavens delivered by the amateur astronomer–minister. Headley Observatory was known as the "Mecca" of British amateur astronomy at that time. Every year in June, Phillips and Millicent would entertain guests at Headley Observatory, including young noteworthies like Steavenson, Frederick James Hargreaves (1891–1970), and Reginald Lawson Waterfield (1900–1986). In the warm summer afternoons, Theodore, Millicent, and guests would stroll along the wildflower covered countryside area of Nottingham.

It is characteristic of Phillips's broad interests in astronomy that in his second presidential address to the BAA, he attacked a theoretical problem rather than an observational topic. At the time, professional astronomer **Herbert Turner** was actively promoting amateur involvement in what is now known as data mining. (See also **Mary Blagg**.) At Turner's suggestion, Phillips undertook the harmonic analysis of the light curves of about 80 long-period variable stars. He demonstrated that those long-period variables could be classified into two groups based on the constancy of the third harmonic in one case but a simple linear relationship between the second and third harmonics in the other. Phillips's study became a classic in the literature of variable-star analysis.

In 1923 Phillips and Steavenson edited a book entitled *Splendour of the Heavens* published by Hutchinson & Company. It first appeared as two volumes containing 979 pages and was very readable, discussing solar and stellar spectroscopy in great detail. It featured almost 1,000 illustrations and numerous fine colored plates that contributed to the book's popularity. Top British astronomers and BAA section directors collaborated as authors of *Splendour*, which was widely used as a text for teaching nonastronomers at the time. Chapters were included on ancient constellations and Chinese astronomy in addition to more conventional astronomical topics. Astronomer Freeman J. Dyson claimed that he learned science more from books than from teachers: "My favorite book was *The Splendour of the Heavens*, a huge and lavishly illustrated compendium of popular astronomy …"

Phillips was honored by the RAS with their presentation of the Jackson-Gwilt Medal and Prize in 1918, and was the first recipient of the BAA's Walter Goodacre Medal in 1930. Just weeks before his death, Oxford University conferred the degree D. Sc. *honoris causa* on Phillips, which fortunately he was able to receive in person.

Robert McGown

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Philolaus of Croton

Born **Croton, (Crotone, Calabria, Italy), *circa* 460 BCE**

Philolaus held that the Universe and everything in it are constituted by the harmonious combination of unlimited and limiting principles.

Philolaus was born in southern Italy, but immigrated to Greece proper, presumably for political reasons. He was active in Thebes until shortly before Socrates' death in 399, and perhaps also in Phlio, a small city near Corinth. The ancient story that **Plato**'s *Timaeus* was plagiarized from Philolaus' only book is surely false, but may be indicative of the latter's interests and outlook. He stated the main Pythagorean tenet as follows: "Everything that is known has number, for without this nothing can be thought of or known" (fr. 5).

Most scholars agree today that the system of the world with a moving Earth, attributed by **Nicolaus Copernicus** and **Galileo Galilei** to the Pythagoreans, was due in fact to Philolaus. In this system the Earth, however, circumambulates not the Sun, as in the systems of **Aristarchus** and Copernicus, but a distinct cosmic source of heat and light, which Philolaus called "hearth of the universe," "house of Zeus," "mother of the gods," and "altar, bond and measure of nature." We earthians cannot see it because it is permanently eclipsed by the "counter-earth," which in turn we cannot see because it constantly shows us its unilluminated face. Ten divine bodies "dance" around the hearth, *viz.*, the firmament of the fixed stars, the five planets, after these the Sun, under it the Moon, then the Earth, and then the counter-earth. The number 10 = 4 + 3 + 2 + 1 was accorded a privileged status by the Pythagoreans. Thus, the counter-earth is not simply postulated *ad hoc* to ensure the occultation of the hearth, but derived so to speak from formal requirements of a well-built world. According to Philolaus, the Sun is like glass, receiving the reflection of the cosmic fire and filtering its light and warmth to us, so that in a sense there are two suns, the primary fire and its mirror image.

Aristotle reports that in this Pythagorean system, the quick motion of all the said bodies was supposed to produce an incredibly strong sound. By assuming that their speeds are in the same ratio as musical concords, it was concluded that the sound caused by the circular movement of the heavenly bodies is a harmony. Because this beautiful "music of the spheres" continually strikes our ears since our birth, we do not hear it.

Roberto Torretti

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Philoponus, John

Born **(Egypt), *circa* 490**
Died **(Egypt), *circa* 570**

John Philoponus (literally "Lover of work"), a Christian philosopher, scientist, and theologian, is one of the most important and certainly most original natural philosophers in Late Antiquity. His life and work are closely connected to the city of Alexandria and the Alexandrian Neoplatonic school. Although the geocentric Aristotelian–Neoplatonic tradition formed his intellectual roots and concerns, he was also an original thinker who eventually broke with that tradition in many respects, helping to lead eventually to the demise of the predominance of Aristotelianism in the natural sciences.

Philoponus' *œuvre* falls into three different parts. First, there are the commentaries on **Aristotle**, which belong to the early period (until about the mid-530s); some of these depend heavily on the lectures of Philoponus' teacher **Ammonius**. Then, in a string of polemical treatises, Philoponus turns to attacking squarely fundamental doctrines of Neoplatonic–Aristotelian natural science. One aim of these treatises may have been to integrate fully the still largely pagan school at Alexandria into a Christian social and intellectual context. In this he failed; leadership of the school remained in pagan hands well into the 6th century. Philoponus seems to have dissociated himself from the school, because from the 540s onward he was writing theological–exegetical works, most importantly a commentary on the biblical creation myth (*De opificio mundi*).

From the point of view of astronomy, Philoponus' two most important contributions to the development of science are his theory of matter and the theory of the impetus, which he seems to have embedded into a whole new view of explaining natural and forced motion of bodies. According to this new theory, the continuation of motion (*e. g.*, of an arrow) is no longer explained by the surrounding medium (air) acting as moved mover (as Aristotle thought), but by invoking the notion of a "force" that is imparted to the moved object by the original mover and that resides in it for the duration of the movement. Philoponus suggests (*De opificio mundi,* I 12) that one might well understand celestial motion in this way, *viz.*, that the celestial bodies have received a powerful impetus at the time of their creation, by which they continue to move in accordance with the will of God.

Philoponus' theory of matter is significant as a landmark in the history of cosmology. He vehemently opposed the Aristotelian dichotomy of the cosmos into a divine, eternal superlunary region and a sublunary region that is subject to generation and corruption. According to him, matter is uniform throughout, and the material basis of the heavens is in fact no different from the material basis of the terrestrial elements and the more complex structures they give rise to. Philoponus' ideas were viciously opposed by the contemporary Neoplatonist **Simplicius**, whose influential writings assured that Philoponus never received the kind of acknowledgment and attention he deserved.

Although this does not play a central role in his writings on natural philosophy, there is enough evidence to suggest that Philoponus was also an expert astronomer. Our oldest description of the construction and use of an astrolabe, written in the first half of the 6th century, is attributed to him; **Theon**'s earlier work on it is now lost. Moreover, we have fairly accurate knowledge of the date of one of his treatises (*De aeternitate mundi contra Proclum*) because he mentions that in the 245th year after Diocletian (529) there occurred a conjunction of all planets in Taurus; since the Sun counted as one of the planets, this conjunction was unobservable and could be inferred only on the basis of long-time observation and theory.

Christian Wildberg

Alternate names

John the Grammarian
John of Alexandria

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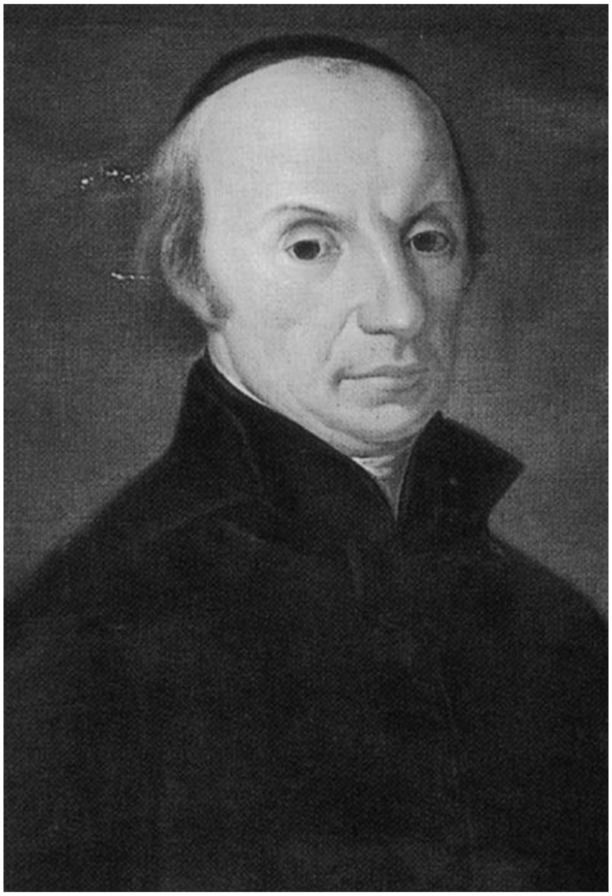
Piazzi, Giuseppe

Born **Ponte in Valtellina, (Graubunden, Switzerland), 16 July 1746**
Died **Naples, (Italy), 22 July 1826**



Giuseppe Piazzi was the discoverer of the first minor planet, (1) Ceres, and published two important star catalogs. Piazzi was the ninth of ten children born to Bernardo Piazzi and his wife, Antonia Francesca Artaria. He came from a family of nobles; his father worked in a land registry office in the Villa di Tirano.

In an age of limited career choices, Piazzi became a Theatine monk in Milan, which gave him the opportunity of broadening his knowledge in the classics and mathematics. He finished his novitiate at the abbey of San Antonio. Studying at Theatine colleges in Milan, Turin, Rome, and Genoa, Piazzi acquired a taste for mathematics and astronomy, earning a doctorate in these subjects. He then taught philosophy at Genoa, mathematics at the new University of Malta (1770–1773), and mathematics at Ravenna (1773–1779). In 1779, Piazzi was appointed professor of dogmatic theology in Rome.

It was not until 1780 that Piazzi found a permanent home when he accepted the chair of mathematics at the Academy of Palermo in Sicily. In 1787, Piazzi became a professor of astronomy and resolved to build one of Europe's finest observatories. He soon obtained a grant from Prince Tomaso d'Aquino Caramanico, Viceroy of Sicily. To equip his new institution, and to facilitate communication with other European astronomers, Piazzi traveled to France and Great Britain. There, he accompanied a group of scientists who were determining the longitude difference between the Paris and Greenwich observatories. While in England, Piazzi became acquainted with Sir **William Herschel** and observed the solar eclipse of 3 June 1788 with Astronomer Royal **Nevil Maskelyne**. But the most substantive result of Piazzi's visit was the 5-ft. vertical circle, a masterpiece of 18th-century technology, which was completed for him by instrument-maker Jesse Ramsden.

In 1789, Piazzi set up his observatory in the Santa Ninfa tower of the royal palace, for the purpose of creating a new catalog of fixed stars, which he considered as the basis of fundamental astronomy. The observatory at Palermo was the southernmost observatory located in Europe and offered unequaled access to the southern skies. Piazzi estimated the possible systematic errors of the Ramsden circle to be between 1 and 3 arc seconds. After a decade of laborious observations, he published his first catalog of 6,748 stars in 1803. With it, Piazzi was able to show that the proper motions of stars are not the exception but the rule. He also made famous the star 61 Cygni, whose abnormally large proper motion led him to call it the "flying star." The Institut de France awarded Piazzi's catalog the Lalande Prize in 1803. Baron **János von Zach**, editor of the *Monatliche Correspondenz* (the world's first astronomical journal), pronounced Piazzi's catalog as "epochal."

Piazzi once described his own personality in a letter to a friend, **Barnaba Oriani**: "My temper is fiery, and even though I am older I cannot suppress it. I have formed many wrong judgments because of it, but even if I am wrong my heart is not bad." Piazzi remained youth-oriented, flamboyant, and inclined to quick judgment. His health was delicate and illness interrupted his observations many times.

Even before publication of his star catalog, Piazzi had become famous. On 1 January 1801, he discovered the "missing planet" between Mars and Jupiter, which he named Ceres Ferdinandea, after the patron goddess of Sicily and its King Ferdinand. While looking for a seventh-magnitude star in Taurus with Ramsden's circle, Piazzi spotted a somewhat fainter object not previously cataloged. He continued to observe the moving point of light until 12 February, after which it became lost in twilight. He was criticized by astronomers all over Europe for not sharing news of his discovery sooner. Thereafter, the Göttingen mathematician **Carl Gauss** calculated the object's orbital elements by a new method that enabled it to be recovered at the end of the same year. Piazzi was subsequently offered the directorship of the Bologna Observatory but declined the invitation.

Piazzi was anxious to create another star catalog, but for all his enthusiasm, his eyesight had begun to fail. By 1807, he had to entrust work on the new catalog to his assistant, **Niccolò Cacciatore**. In 1813, Piazzi published the second catalog of 7,646 stars; it too received a prize from the Institut de France.

During this period, Piazzi was charged by the government of Naples with renovating the system of weights and measures used in Sicily. In 1808, he published an essay on the subject and was given another annual pension by King Ferdinand for establishment of the metric system. In turn, the Great Comet C/1811 F1 prompted him to publish his views on its nature. Piazzi supposed that comets were not formed along with the planets, but were produced from time to time in deep space, where they eventually dissipated.

In 1817, Piazzi was invited to Naples to examine the Capodimonte Observatory being constructed there. Though he at first declined the invitation to become its director, Piazzi finally agreed to become director-general of both the Naples Observatory and the Palermo Observatory. King Ferdinand gave him 93,500 lire in value of land, which he could sell or administer as he wished. Piazzi was also appointed president of the Royal Academy of Sciences in Naples; Cacciatore succeeded him as director of the Palermo Observatory. While at Naples, Piazzi introduced many innovations but sorely missed Palermo.

Piazzi received an unusual honor from admiral **William Smyth**, the son of an American-born loyalist who came to England after the Revolution. Smyth was also an astronomer and became acquainted with Piazzi. When the admiral's son was born in 1819, he was named **Charles Piazzi Smyth** and later became the Astronomer Royal for Scotland.

In 1825, Piazzi wrote, "It is a month since I have been in Naples, having left Palermo with regrets. Perhaps I will never see it again." The following year, he succumbed to cholera. In 1871, his native village remembered him by erecting a statue in Piazza Luini. Minor planet (1000) is named Piazzia in his honor.

Clifford J. Cunningham

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Picard, Jean

Born **La Flèche, (Sarthe), France, 21 July 1620**
Died **Paris, France, 12 October 1682**

Jean Picard made notable contributions to early precision astronomy, geodesy, cartography, and hydraulics. Picard, the son of a bookseller, attended lectures at the Jesuit College of La Flèche, where **René Descartes** had been a student. He studied Greek and Latin literature and theology, and was initiated to astronomy during a course on Aristotelian philosophy. Picard's earliest known astronomical work occurred on 21 August 1645, when he assisted **Pierre Gassendi** in the observation of a solar eclipse. He also attended Gassendi's lectures on astronomy at the Collège de France in Paris. Like his mentor, Picard became an ordained priest (1650) and then traveled throughout Europe, learning the Italian and German languages. He held several ecclesiastical positions, as *abbé* and *prieur* at Rillé and Brion, and was also a schoolmaster. By and large, his astronomical studies were conducted privately, although Picard became an informal member of the Académie de Montmor.

Together with **Adrien Auzout** and **Pierre Petit**, Picard devised a movable-wire (filar) micrometer and used it to measure the angular diameters of the Sun, Moon, and planets. In 1666, he was named a member of the Académie royale des sciences, an appointment that brought Picard's astronomical and geodetic skills to the fore. Thereafter, he applied both telescopic sights and cross hairs to other scientific instruments used for angular measurements, chiefly quadrants and sectors, and proposed that meridian observations be conducted by the method of corresponding heights. His assistant, **Philippe de la Hire**, was the first to implement Picard's suggestion of establishing a mural quadrant in the meridian plane (1683).

Armed with these newer techniques, Picard undertook his principal investigation, namely the measurement of an arc of the meridian. Supported by the Académie des sciences, this operation sought to determine a more precise value for the radius of the Earth. Picard employed the method of skeleton triangulation along the meridian between Paris and Amiens. His results, published as *La Mesure de la Terre* (1671), attained a precision some 30 to 40 times greater than previously achieved. Picard's meridian line eventually led to the first accurate trigonometric survey of France. He subsequently applied these methods to the creation of a precision map of the Paris area (*Carte des Environs de Paris*, 1678), which superseded all former cartographic ventures.

In 1671, Picard traveled to **Tycho Brahe**'s former observatory on the island of Hven to accurately determine its location, so that Brahe's observations could be compared directly with those at Paris. Picard (at Hven) and **Jean Cassini** (at Paris) used observations of the eclipses of Jupiter's satellites to determine the longitude difference of the two observatories. It was the first attempt to employ this method simultaneously, which was made possible by the ephemerides of Jupiter's satellites prepared by Cassini. During this project, Picard observed an annual displacement of the pole star (Polaris), which was not explained until 1728 by **James Bradley** as due to the combined effects of nutation and the aberration of starlight.

Picard brought back to Paris his Danish assistant, **Olaus Römer**, and a copy of Brahe's registers of observations. In 1673, he moved into the newly constructed Observatoire de Paris, where Cassini was installed. Picard participated on several expeditions to determine precise coordinates of various cities and harbors, for the purpose of creating a new map of France. This map, drawn and published by de la Hire (1693), afforded corrections as great as 150 km in longitude and 50 km in latitude over previous cartographic methods.

Picard also played a role in hydraulics, helping to solve the problem of supplying water to the fountains at Versailles. He oversaw the survey when the Grand Canal was dug in order to create artificial ponds or tanks needed to supply the fountains. Out of this survey arose Picard's correction of the apparent level, due to the curvature of the Earth. His posthumous treatise on the subject, *Traité du Nivellement* (1684), became a standard reference for more than a century.

In 1982, an international conference was held at Paris to commemorate the tercentenary of Picard's death and to highlight his role in the institutionalization of science in France during the 17th century.

Raymonde Barthalot

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Piccolomini, Alessandro

Born **Siena, (Italy), 13 June 1508**
Died **probably Siena, (Italy), 12 March 1579**

Alessandro Piccolomini is best known for producing the first star atlas, in 1540, with 47 star maps designed for the general reader.

Piccolomini was born into an illustrious family whose members included Pope Pius II and Pope Pius III. As a young man in his hometown of Siena, he joined the Accademia degli Intronati, an organization that fostered the development of the use of Italian as a literary language on par with Latin. Around 1538 Piccolomini moved to Padua, where he eventually became a professor of philosophy at the university and joined the Accademia degli Infiammati, a group that promoted Italian works as well as had an interest in the fields of astronomy and mathematics. Piccolomini rose in the ranks of the church and in 1574 became the Archbishop of Patras, in Greece. He never went to Greece, however, and remained in Italy as coadjutor to the Archbishop of Siena until his death. During his lifetime Piccolomini was an important literary and philosophical figure, writing numerous comedies, sonnets, and philosophical treatises, and translating several classical works into Italian.

Although not an astronomer, Piccolomini did produce a few treatises on mathematical astronomy. These works were written in Italian because of his strong interest in promoting the literary use of the language. Piccolomini's first astronomical work was *De la sfera del mondo* (On the sphere of the Universe, Venice, 1540), a cosmographical work in which he defends the Ptolemaic universe. Though there are a few inferences in later editions that hint at a sympathy with the Copernican system, Piccolomini constantly supported the Ptolemaic viewpoint throughout his life. In his *Della filosofia naturale* (On natural philosophy, Rome, 1551) he mounted a staunch defense of a central and immovable Earth. His most original astronomical work was his *La prima parte dele theorique ovvero speculationi dei pianeti* (Part one of the theories or speculations of the planets, Venice, 1558), in which he endeavored to save the appearances of the motions of the planets in terms of the Ptolemaic theory. Piccolomini particularly noted that the Ptolemaic theory does not represent reality but is merely a useful tool for the astronomer.

Piccolomini's best-known astronomical work is undoubtedly *De le stele fisse* (On the fixed stars, Venice, 1540), his companion volume to *De la sfera del mondo*. *De le stele fisse* is famous as being the very first star atlas and contains a series of woodcut star maps that seem particularly suited to the casual stargazer. The two books were dedicated to Laudomia Forteguerri, and designed so that she, and any other reader, would be able to recognize the different constellations and find them in the sky. The atlas proved to be quite popular with readers and went through at least 12 editions from 1540 to 1595. Piccolomini produced 47 star maps for the book, one for each of the Ptolemaic constellations except for Equuleus, which he considered too insignificant for inclusion. Unlike previous depictions of the constellations, he did not draw in the mythological images associated with them, and so they appear as simple star patterns. Piccolomini included stars from **Ptolemy**'s first through fourth magnitudes, omitting the fainter fifth magnitude stars, and used different star symbols for each of the magnitude classes. The stars were also labeled a, b, c, d, *etc*., usually in order of their brightness. The accompanying text helps to explain the particulars about each constellation, including the legends associated with them. In the individual maps the constellations are drawn to fill the page and, therefore, the different maps are not to the same scale. They are also drawn so that the traditional constellation pattern is most recognizable and so the direction of north varies from one map to the next. There is also a lack of a coordinate grid on the maps; no coordinates are listed on the subsequent star tables, and little attention is paid to the accuracy of star positions with respect to each other. As a result, *De le stele fisse* was not of much use to professional astronomers, but this is not surprising as Piccolomini was writing for a more popular audience.

Some sources incorrectly list 1578 as the year of Piccolomini's death.

Ronald Brashear

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Pickering, Edward Charles

Born **Boston, Massachusetts, USA, 19 July 1846**
Died **Cambridge, Massachusetts, USA, 3 February 1919**

Edward Pickering created the world's largest programs in photometric, photographic, and spectroscopic stellar research. These programs helped American astronomy to attain a dominant role within the discipline by the early 20th century.

Pickering was the son of Edward and Charlotte (*née* Hammond) Pickering. The Pickering family had deep roots in Massachusetts; Edward's ancestor John Pickering had emigrated from England to Salem in 1636. Edward was born into a family well connected with people of influence in Boston. He attended Boston Latin School, but his interest in science developed during studies at Harvard College's Lawrence Scientific School. On his graduation at age 19, Pickering taught mathematics at the Lawrence School for 2 years before becoming an instructor in physics at the Massachusetts Institute of Technology [MIT]. At the age of 22, he was appointed Thayer Professor of Physics at MIT, and in 1874, he married Elizabeth Wadsworth Sparks, daughter of former Harvard president Jared Sparks. The couple had no children. Upon the death of **Joseph Winlock**, Pickering was named the fourth director of the Harvard College Observatory, an office he assumed on 1 February 1877. He would remain the observatory's director until his own death. Initially named Phillips Professor, Pickering would be renamed Paine Professor of Astronomy when that position was created in 1887.

Pickering is remembered as a pioneer in the new science of astrophysics. On becoming director of the observatory, he decided not to focus on the astronomy of stellar positions and motions, a research field that occupied many of the large observatories of the day. Instead, he began by emphasizing a still undeveloped field, the measurement of the brightnesses of stars. In 1884, Pickering published *Harvard Photometry*, a catalog of the visual magnitudes of 4,260 stars. In this and later works, Pickering adopted British astronomer **Norman Pogson**'s proposal that a difference of five magnitudes should correspond to a brightness ratio of 100 times. The Pogson scale was soon universally adopted, in part because of Pickering's advocacy. *Harvard Revised Photometry*, a catalog of the visual magnitudes of 9,110 stars brighter than magnitude 6.5, followed in 1908. A supplement to this catalog included measurements of the magnitudes of 36,682 additional stars.

In order to achieve worldwide coverage of the sky, it was necessary for Pickering to establish an observing station in the Southern Hemisphere. Pickering's brother, **William Pickering**, helped found Harvard's Boyden Station at Arequipa, Peru, in 1891. The bulk of the Peruvian photometric observations, however, were acquired and reduced by another member of the observatory staff, **Solon Bailey**. Rather than employing the technique of an artificial comparison star, Pickering's early photometric measurements were chiefly conducted by the polarization method, wherein the magnitudes of two stars were visually compared.

The magnitudes in *Harvard Revised Photometry* are visual magnitudes. His brother, however, convinced Pickering of the advantages of astronomical photography, after sensitive dry emulsions for photographic plates were developed. Many stars could be recorded on a single exposure, and the photograph became a permanent record that could be examined at leisure. Starting in the 1880s, the Harvard College Observatory also pioneered the development of photographic photometry. With data-collection facilities located in both hemispheres, the observatory accumulated an unmatched archive of photographic plates of the heavens. In 1903, Pickering published the first *Photographic Map of the Entire Sky*, a set of 55 photographs that showed stars as faint as the 12th magnitude.

Variable stars were another focus of research at the Harvard College Observatory under Pickering's directorship. In 1881, he proposed a system for classifying the types of variables that were known. Later, Pickering's assistant, **Henrietta Leavitt**, discovered the period–luminosity relationship among Cepheid variable stars, by examining photographs of the Small and Large Magellanic Clouds obtained at Harvard's southern station. Bailey likewise employed photography to discover more than 500 variable stars in globular clusters. When Pickering assumed the directorship, only some 200 variable stars were known. At the time of his death, however, more than 3,000 variable stars had been discovered at the observatory, almost all by photographic methods.

Pickering provided technical support and encouragement to **William Olcott** after the latter founded the American Association of Variable Star Observers [AAVSO] in 1911. The early AAVSO had a membership that included professional astronomers like **Anne Young** as well as amateur astronomers.

Pickering initiated routine patrol photography of the sky with wide-field cameras. These patrol photographs provide an important record of the appearance of the sky in times past and are another of Pickering's legacies.

Under Pickering's directorship, the observatory carried out spectroscopic investigations that were perhaps even more important than its photometric programs. In 1885, Pickering initiated a program of objective prism spectroscopy. A thin prism was placed in front of the objective lens of a wide-field telescope. The images of many stellar spectra could then be recorded on a single photographic plate. In 1889, he reported the discovery of the first spectroscopic binary star, ζ Ursae Majoris.

When Pickering began this spectroscopic work, several systems had already been proposed for classifying stellar spectra. These systems, based primarily on visual observations, had stars grouped into only a handful of spectral types. Yet, all of them proved inadequate to the wealth of details revealed by the new photographic surveys. At Harvard, new classification schemes were developed for the thousands of stellar spectra acquired by the objective prism surveys.

The first Harvard spectral catalog, the *Draper Memorial Catalogue*, was published in 1890, and classified 10,351 stars into 15 spectral types. The second Harvard catalog, initiated by Pickering's assistant **Antonia Maury**, abandoned the original Draper scheme and substituted 22 groups represented by Roman numerals. Maury's system incorporated further subdivisions based on the widths of certain spectral lines. However, the next Harvard catalog, produced by **Annie Cannon**, returned to an elaboration of the Draper scheme. It was this catalog that introduced the now familiar sequence of spectral types, OBAFGKM, along with their decimal subdivisions. Pickering lobbied for acceptance of this classification system at the 1910 meeting of the International Union for Cooperation in Solar Research. A committee on the classification of stellar spectra was formed, which gave support to the Harvard system. That system gained worldwide acceptance, and was the forerunner of the MKK spectral classification system widely used today.

In 1911, Pickering began a more ambitious program in the spectral classification of stars, which culminated in publication of the *Henry Draper Catalogue*. Therein, Cannon classified the objective prism spectra of some 225,300 stars of the ninth magnitude and brighter. Although the bulk of her classification work was completed by 1915, publication of the *Henry Draper Catalogue* was completed only after Pickering's death by his successor, **Harlow Shapley**.

Abundant recognition came to Pickering during his lifetime. Among his awards were two Gold Medals from the Royal Astronomical Society, a knighthood of the Prussian Order *Pour la Mérite*, and the Bruce Medal of the Astronomical Society of the Pacific. He received honorary degrees from six American and two international universities. At the age of 27, he was elected to the National Academy of Sciences. Pickering played a role in the formation of the American Astronomical Society [AAS] (founded in 1899) and in 1905 was elected its second president, a post he likewise held until his death.

When Pickering was chosen president of what was then called the Astronomical and Astrophysical Society of America [AASA], the organization had met for only 6 years. During his long presidency, the society changed its name to the AAS and became a more effective instrument for fostering the development of an increasingly professional science. Pickering presided over the establishment of numerous research committees that, with varying degrees of success, attempted to encourage cooperation among astronomers and to establish professional standards within the discipline. From its inception, the AAS was an organization that served chiefly the interests of professional astronomers. Pickering was sympathetic to amateurs, but during his presidency, the society's membership and direction were firmly consolidated in professional hands.

While Pickering himself performed the bulk of measurements for his visual photometric surveys, numerous women assistants helped to carry out the photographic and spectroscopic programs he supervised. The Harvard College Observatory under Pickering's tenure has been likened to a factory system of mass production, with Pickering as the observatory's chief executive officer. Pickering saw astronomy as a field in which women could make important contributions to science. Yet, most of the women hired under Pickering's directorship were consigned to routine work in the reduction of astronomical data. Even so, his assistants Maury, Leavitt, Cannon, and **Williamina Fleming** were among the most important women astronomers of their time.

Pickering never abandoned his belief in the importance of securing large collections of astronomical data. Toward the end of his life, this emphasis caused friction with some younger astronomers who emphasized research programs driven by astrophysical questions over data gathering. Even these critics, however, appreciated the significance of Pickering's data and its ready availability to the astronomical community.

Pickering's papers (comprising 68 linear feet) are in the Harvard University Archives.

Horace A. Smith

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Pickering, William Henry

Born **Boston, Massachusetts, USA, 15 February 1858**
Died **Mandeville, Jamaica, 16 January 1938**

William Pickering influenced the selection of mountaintop sites for astronomical observatories in the Western Hemisphere, pioneered the application of photography to astronomy, and was a noted popularizer of the discipline. His later works concerned visual observations of the Moon and planets, but in this regard, he strayed progressively further from mainstream science.

Pickering was descended from a notable New England family; his parents were Edward and Charlotte (*née* Hammond) Pickering. His older brother, **Edward Pickering**, was appointed director of the Harvard College Observatory, [HCO] in 1877. William graduated from the Massachusetts Institute of Technology in 1879 and taught physics there until 1883. In 1887, he was named an assistant professor at HCO. But while retaining this title until his retirement in 1924, Pickering fashioned for himself an eclectic and peripatetic career.

Pickering and his brother were the first to recognize the favorable seeing conditions that existed on California's Mount Wilson in 1889. He subsequently mounted Harvard's Boyden refractor at the site and conducted photographic studies. Roughly a decade elapsed before **George Hale** performed similar tests at Mount Wilson, prior to establishing his solar and astronomical telescopes on the mountain's peak. In 1891, meanwhile, Pickering reerected the Boyden telescope at Arequipa, Peru, to further his brother's photometric and photographic program on Southern Hemisphere stars. There, he devised a standard scale (from 1 to 10) for rating the atmospheric seeing conditions.

But the routine acquisition of data proved unsuitable for Pickering, whose attention was directed instead toward visual studies of the planets, particularly Mars. After being recalled to Massachusetts, Pickering became acquainted with **Percival Lowell**, and was soon commissioned by him to establish an observatory near Flagstaff, Arizona. Pickering thus played a role in the founding of three American observatories, and demonstrated the advantages of arid, high-altitude conditions for the optimization of astronomical research.

Pickering's early success with dry-plate emulsions convinced his brother of the enormous potential of photographic methods for astronomical data collection. This opportunity was soon exploited by Edward as one of three great programs that he established at Harvard. On behalf of the observatory, Pickering then undertook an expedition to Jamaica in 1899. Finding its atmospheric conditions suitable, he returned the following year with a 12-in. refractor of 135-ft. focus. With it, Pickering secured some of the finest images then obtained of the Moon's surface, which were published in his photographic atlas (1903).

From his lunar studies, Pickering argued for the volcanic origins of most lunar surface features. He concluded that the rival impact theory could not explain the uniform circularity of craters. In support of this hypothesis, Pickering amassed geological evidence from places as widely separated as the Hawaiian Islands and the Azores, and drew from it what he believed to be convincing analogies for the volcanic nature of the Moon's features. On the basis of albedo changes that he observed during the course of each lunar "day," Pickering advanced suggestions that either hoarfrost, or some type of vegetation, could explain the apparent phenomena, despite the absence of any measurable lunar atmosphere.

Much of Pickering's later life was devoted to the search for a trans-Neptunian planet. Starting in 1907, he predicted the existence of no less than seven unseen worlds over the next 24 years. Names for Pickering's hypothetical planets bore letters of the alphabet, starting with "Planet O." He employed a simplified graphical process to analyze the measured residuals of Uranus and Neptune. While none of Pickering's hypothetical planets were found to exist, his search nonetheless catalyzed a similar investigation at Lowell Observatory, from which the eventual discovery of Pluto was announced in 1930.

Pickering's most notable discovery, on photographic plates taken at Peru, concerned Saturn's ninth satellite (Phoebe) and his demonstration of its retrograde orbit. Phoebe was the first planetary satellite found to possess this property. For his investigations of the Saturnian system, Pickering was awarded the Lalande Prize of the Paris Academy of Sciences in 1905 and the Janssen Medal in 1909. Nonetheless, his scientific methods remained largely those of the 19th century. Pickering's visual observations and highly speculative theories were greeted with increased skepticism and ostracism by 20th-century astronomers.

Pickering was married to Anne Atwood; the couple had two children. A crater on the Moon bears his name.

Jordan D. Marché, II

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Pigott, Edward

Born **England or France, 1753**
Died **Bath, England, 27 June, 1825**

Edward Pigott's chief claim to fame is as one of the founders of the study of variable stars.

Pigott was the son (probably the oldest) of Nathaniel Pigott and Anna Mathurina de Beriol. Nathaniel was the grandson of William, Eighth Viscount Fairfax; Edward's full name is sometimes given as Edward Fairfax Pigott. Little is known of Edward's early life and formal education, although he appears to have acquired a good knowledge of French. A portrait in the Junior School of Ampleforth College, Yorkshire, England, long believed to be of Edward Pigott (and published as such) may, in fact, be that of a relative, Gregory.

Nathaniel Pigott was a surveyor and astronomer. Edward's interests in these subjects were probably stimulated by helping his father. They observed the 3 June 1769 transit of Venus together from Caen, France (where they then lived), and many years later, the 3 May 1786 transit of Mercury from Louvain, Belgium. In 1771, the family moved to Wales.

Edward Pigott surveyed the region of the Severn estuary in 1778/1779, discovered a nebula in Coma Berenices in 1779, and the short-period comet D/1783 W1. He also made observations of the satellites of Jupiter and studied the method of longitude determination by lunar transits and is believed to have observed the great comet of 1807.

In 1781 the family moved to Bootham, Yorkshire, where father and son constructed an observatory. There, Edward began a partnership with **John Goodricke**, discoverer of the periodicity of the light variation of Algol (β Persei). Pigott himself discovered the variability of η Aquilae on 10 September 1784. By early December of the same year, he had determined its period to be 7 days, 4 hours, 38 minutes, about 24 minutes longer than the accepted modern period. Piggott tried to set up a photometric system so that he could estimate the variations in stellar brightness more precisely.

It was not until the 17th century, after the application of the telescope to celestial observation, that astronomers began to accept that the brightness of some stars varied. Pigott and Goodricke were the first to show that stellar variability is often periodic. Pigott has some claim to be regarded as the founder of the study of stellar variability. In 1786, he published a catalog of 50 variable stars writing, "these discoveries may, at some future period, throw fresh light on astronomy." Later he announced the variability of the stars now known as R Scuti and R Coronae Borealis. During a lull in the Napoleonic wars, Pigott returned to the continent but was caught by a renewal of hostilities and detained for a while at Fontainebleau, where, nevertheless, he managed to write a new study of the period of R Scuti and tried to explain stellar variability in terms of a model of rotating spotted stars. He also inferred the existence of "dark stars" and surmised that aggregations of such objects might account for phenomena like the "Coal Sack." Pigott was apparently released from detention through the good offices of Sir Joseph Banks. Although Pigott knew Banks and both the **Herschels** (**William** and **John**), and published some 20 papers in the *Philosophical Transactions of the Royal Society of London*, he does not seem to have received much recognition for his work during his lifetime. He is known to have retired to Bath and appears to have withdrawn from astronomical work by the end of his life.

Alan H. Batten

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Pingré, Alexandre-Guy

Born **Paris, France, 4 September 1711**
Died **Paris, France, 1 May 1796**

Alexandre Pingré was a diligent observational astronomer, calculator, and noted historian of astronomy. Pingré's parents sent him to the college of Senlis directed by the regular canons of the Congregation of France (the Génovéfains). A good student, he entered the Congregation at age 16. By 1735 he was a teacher of theology in the college. Because of the persecutions against the Jansenistes, Pingré was dismissed from his chair and sent away from Paris to obscure colleges to teach grammar. Fortunately, in Rouen, Pingré met the surgeon Claude-Nicolas Le Cat who, in 1749, asked him to join—as an astronomer—the academy he had founded there. Thus, at the age of 38, Pingré undertook his first scientific work by calculating the lunar eclipse of 23 December 1749; 4 years later he observed the transit of Mercury on 6 May 1753. The Académie royale des sciences in Paris then named Pingré a correspondent of **Pierre-Charles Le Monnier**, and his congregation called him to Paris, to the abbey of Sainte-Geneviéve, where the abbot installed a small observatory and offered him some instruments. In Paris Pingré met Le Monnier, who assigned him the calculations for the four-volume *Etats du Ciel à l'usage de la marine*, which appeared from 1754 to 1757. Later, **Joseph-Jérôme Lalande** integrated this nautical almanac into the *Connaissance des temps*. In 1756, Pingré became a member of the academy.

For the second edition (1770) of the *Art de vérifier les dates* of **Nicolas La Caille**, Pingré calculated the solar eclipses up to 1900 and later (1787) the eclipses in the Northern Hemisphere for 10 centuries before our era. Pingré designed several sundials in Paris. At the request of the Provost of the Guilds, he created in 1764, on the tower-column of the former Hôtel de Soissons, a very original sundial, cylindrical with several horizontal stilettos.

In 1760, the academy designated Pingré to observe the 1761 transit of Venus from Rodrigue Island in the Indian Ocean. He also made three voyages to examine the marine chronometers of Berthoud and Le Roy. During one of these voyages, he observed the 1769 transit of Venus from Cap François in Santo Domingo, Haiti. From the numerous observations of the transit received in Paris, Pingré deduced a solar parallax of 8.8″.

In 1769, Pingré was named astronomer–geographer in the place of the deceased **Joseph Delisle**. At the same time he was chancellor of the University, librarian of the Sainte-Geneviéve Library, and a member of the Académie de marine.

Besides his regular observations, Pingré wrote lengthy works, interrupted from time to time by his travels. Beginning in 1757, he undertook research on comets from Antiquity. This large historical and theoretical work, *Cométographie*, was published in two volumes in 1783/1784. From 1756, he worked on a history of 17th-century astronomy at the request of Le Monnier, who passed to him the manuscripts of **Ismaël Boulliau**. Pingré completed this work at the age of 80. Jerôme de Lalande reported on it to the academy in 1791 and then, with Le Monnier, undertook its publication. Upheaval during the Revolution halted printing. The manuscript was located by **Camille Bigourdan** in the archives of the Paris Observatory; Bigourdan published it in 1901.

At Lalande's request Pingré translated the *Astronomiques* of **Manilius**, a Latin poet of the Augustan century, and a poem by **Aratus**. During the Revolution, with the suppression of the academies, Pingré remained the librarian of Sainte-Geneviéve but with few resources. With the establishment of the Institut National in 1795, he was elected to the astronomy section, attending meetings almost until his death.

A regular canon of Sainte-Geneviéve, Pingré was also a dignitary of freemasonry, being an active correspondent with the lodges of Bourbon Island (now Réunion). His leisure activities included reading (in particular Horace in Latin), music, and, at the end of his life, botany. Esteemed as a scientist, he was also a man of great goodness, modesty, and piety.

Simone Dumont

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Pişmiş, Paris Marie

Born **Istanbul, (Turkey), 1911**
Died **Mexico City, Mexico, 1 August 1999**

Paris Pişmiş was the first formally trained astronomer in Mexico. She was born into an Armenian family living in Istanbul, Turkey. In defiance of her parents' wishes and native tradition, she became one of the first women in Turkey to attend Istanbul University, earning her Ph.D. in mathematics in 1937, under the supervision of professors **Erwin Freundlich**, who was then in Istanbul as a refugee from the Nazi persecution, and Richard von Mises. Pişmiş worked as a research assistant at the Istanbul University Observatory from 1935 to 1937.

Before World War II, Pişmiş traveled to the United States to pursue postdoctoral studies. She worked as an assistant astronomer at the Harvard College Observatory (1938–1942). There, she met astronomers **Harlow Shapley**, **Bart Bok**, **Sergei Gaposhkin**, **Cecilia Payne Gaposhkin**, and **Donald Menzel**. Pişmiş also met Félix Recillas, a Mexican mathematician and an astronomy student who became her husband in 1942. In that year, she moved with him to Mexico and joined the staff of the newly created Tonantzintla Observatory in Puebla, where she worked alongside **Guillermo Haro**, who became the observatory's director. Pişmiş started teaching astronomy to students of physics and mathematics. Her two children, Elsa and Sevín Recillas, who also became scientists, were born during that time.

After visiting appointments at Princeton University and Yerkes Observatory, Pişmiş moved to Mexico City in 1948 and joined the Observatorio Astronómico Nacional de Tacubaya, part of the Universidad Nacional Autónoma de Mexico [UNAM], which is now the Instituto de Astronomía. She spent most of her time on research, teaching, and advising students. At UNAM, Pişmiş taught formal courses in astronomy, and transmitted her passion for doing scientific research to many students (*e. g.*, Arcadio Poveda, Eugenio Mendoza, Enrique Chavira, and others).

Pişmiş was also a restless traveler and was engaged with different groups doing astronomical research all over the world. She was always interested in new ideas and new techniques. She was invited to lecture at many scientific institutions and universities, traveling to Istanbul, Heidelberg, Ankara, Byurakan, the Canary Islands, Paris, Buenos Aires, and so forth.

Pişmiş made significant contributions in observational and theoretical astronomy. She discovered 20 open stellar clusters and three globular clusters that are named for her. She was among the first to study the kinematic behavior of the gas associated with hot young stars, introducing the Fabry–Perot interferometric technique to Mexico. Pişmiş studied the effects of interstellar absorption in the observed distribution of star clusters. She performed the first photometric observations of young stellar clusters carried out in Mexico. She also worked theoretically to explain the origins of spiral structures in galaxies and the observed galactic velocity fields. Toward the end of her life, Pişmiş became interested in the morphology and kinematics of the so called mildly active galactic nuclei. Her scientific output totaled more than 100 research articles.

Another of Pişmiş's major contributions was to foster the publication of Mexican astronomical journals. She was a member of the board of editors of the *Revista Mexicana de Astronomía y Astrofísica*, from its foundation in 1974 untill her death. She was editor of the *Boletín de los Observatorios de Tonantzintla y Tacubaya*, from 1966 to 1973. Pişmiş was likewise editor of the proceedings of the International Astronomical Union Colloquium 33 (*Observational Parameters and Dynamical Evolution of Multiple Stars*) in 1975. She supervised the edition of three volumes of the *Astrophotometric Catalogue of Tacubaya* (1966).

Pişmiş was a member of the International Astronomical Union, and was appointed Mexico's representative to that organization. She was a member of the Royal Astronomical Society, the American Astronomical Society, and the Academia Mexicana de Ciencias. She received a science teaching award from UNAM, plus honorary doctorates from the same institution and from the Instituto de Astrofísica, Óptica y Electrónica.

Paris's former student, Deborah Dultzin, wrote:

> Listening to her lectures, learning to observe with her, and later on, being initiated into the wonderful world of scientific research work by her, was an inspiring experience. She spoke about a scientist's life as something wonderful for a woman, and one could see that she really enjoyed it.

Pişmiş was interested not only in science, but also in all aspects of culture. Fluent in several languages, she loved literature, painted, played the flute and piano, and was also a good singer and dancer. She inspired admiration in all those who knew her, and was a role model for women in science all over Mexico and beyond. In collaboration with her grandson, Gabriel Cruz-González, Pişmiş prepared an autobiography, *Reminiscences in the Life of Paris Pişmiş: A Woman Astronomer* (1998).

Nidia Irene Morrell

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Plana, Giovanni Antonio Amedeo

Born **Voghera, (Lombardy, Italy), 6 November 1781**
Died **Turin, Italy, 20 January 1864**

Mathematical physicist and astronomer Giovanni Plana wrote more than 100 memoirs dealing with mathematical analysis, geodesy, astronomy, celestial mechanics, and heat theory, including his most important work, the theory of the lunar movements. Plana was the son of Antonio Maria Plana and Giovanna Giacoboni. From 1796, Plana studied in Grenoble, France, where he met and befriended Stendhal (Henry Beyle). In 1800, Plana entered the École Polytechnique where **Joseph Lagrange** taught analysis and mechanics, Gaspard Monge taught geometry, and **Pierre de Laplace** taught astronomy. He also became friends with **Siméon-Denis Poisson**. In 1803, Plana became professor of mathematics at the Turin Artillery School, located in Alessandria, and became professor of astronomy at Turin University in 1811. Before assuming the responsibilities of his chair, Plana practiced astronomy at the Brera Astronomical Observatory in Milan under the scientific direction of **Barnaba Oriani**. In 1816, he became director of the Turin Astronomical Observatory. In 1817, Plana married Alessandra Maria Lagrange, a niece of the great mathematician.

In Milan in 1811, Oriani proposed to the young astronomer **Francesco Carlini** some research in the theory of the Moon, probably on Laplace's suggestion. Plana was involved with this project and collaborated closely with Carlini, at least until 1820, when they won a prize of the Paris Académie des sciences. The prize, promoted by Laplace in 1818, was to be assigned to whoever succeeded in the construction of lunar tables based solely on the law of universal gravity. (The prize was shared with **Charles Damoiseau**.) Despite the prize, Laplace criticized the memoir of Carlini and Plana. A bitter dispute ensued. Plana determined the tone of the dispute, perhaps remembering the discussions in Grenoble when the young students sided excitedly with Lagrange, *homme à principes*, or with Laplace, *homme à théorèmes.* In the end, Laplace admitted that the two Italian astronomers were more accurate than him. The Académie des sciences published Damoiseau's memoir but not that of Carlini and Plana, who decided to publish a complete theory of the Moon. But the collaboration was complicated and, in the end, Plana decided to continue his work alone, which was published in 1832 in three big volumes.

Plana's work is considered a milestone in celestial mechanics. The theory was derived solely from the principle of universal gravitation and borrowed only the essential data from the observations. Plana's lunar theory had completed Laplace's program, along the road drawn by **Isaac Newton**, for one of the most complex celestial phenomena.

In 1825 and 1827, Plana and Carlini published the data of their observations obtained by the measurement of the mean parallel (45°) linking the French geodesic net to the northern Italian one, from Bordeaux to Fiume (today Rijeka), crossing the Alps. They were also able to explain the anomalies of Giovanni Battista Beccaria's measurements of the meridian arc between Mondovì and Andrate, as they noted the deviation of the plumb line due to the presence of high mountains.

In 1822, Plana inaugurated the new Turin Observatory and the new instrument, a meridian circle of Reichenbach. He published the results of his 1822, 1823, 1824, and 1825 observations and his theoretical considerations on astronomical refraction. Other astronomical memoirs dealt with Foucault's pendulum, the movement of a body launched from the Moon to the Earth, and comets.

Plana won the Copley Medal of the Royal Astronomical Society. He was president of the Turin Accademia delle Scienze, foreign member of the Académie des sciences, and corresponding member of the most important European academies. Plana's archives are in Turin in the Accademia delle Scienze. Plana's letters to Carlini about the theory of the Moon and other subjects are in the Archives of the Brera Astronomical Observatory.

Pasquale Tucci

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Plancius, Petrus

Born **Dranoutre, (Belgium), 1552**
Died **probably Amsterdam, The Netherlands, 1622**

Petrus Plancius is known as a cartographer and globe maker, and also as a Calvinist theologian and Bible scholar. Plancius's education took him to England and France; he subsequently moved north from Flanders during the Dutch Wars of Independence and settled in the Netherlands. His interest in missionary work arose from his religious convictions, and gave impetus to his cartographic activities, both celestial and terrestrial.

Plancius's 1589 celestial globe, published with **Michael van Langren**, included Southern Hemispheric stars that had not been previously depicted, namely *Crux*, *Triangulum Antarcticus*, and the *Nubeculae Magellani*. He encouraged **Pieter Keyser** and Frederick de Houtman to make further observations of the southern skies during the voyage of the *Hollandia* to the East Indies in 1595–1597. These observations supplied the data for the formation of 12 further constellations, which appeared on Plancius's globe of 1598 published by Hondius and which were subsequently adopted by **Johann Bayer**. On a globe published in 1612 with Pieter van den Keere, Plancius added another eight constellations, in between old ones. Some of these, of biblical reference, have not survived; others such as Monoceros, Camelopardalis, and Columba have endured.

Peter Nockolds

Alternate name

Platevoet, Petrus

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Planman, Anders

Born **Hattula, (Finland), 1724**
Died **Pemar, (Finland), 25 April 1803**

Anders Planman observed the transits of Venus in 1761 and 1769 for the Swedish Academy of Sciences. Planman, the son of lieutenant Pehr Planman and Ingeborg Leufstadius, was born in a Swedish family in Finland (then part of Sweden). He studied in Åbo (Turku) and Uppsala, where he became associate professor (*docent*) in astronomy in 1758. In 1763, Planman became a professor of physics in Åbo, where he remained until his retirement in 1801. He was a member of the Science Society at Uppsala (*Vetenskapssocieteten*) and from 1767 of the Royal Swedish Academy of Sciences.

Planman's most important contribution in the field of astronomy came with the transits of Venus in 1761 and 1769, which he observed in the far north of Finland. Planman's expeditions were financed by the Academy of Sciences in Stockholm, and they were part of a larger effort by Swedish astronomers to contribute to the measurement of the solar parallax, which they did to an extent second only to Britain and France. Though his own 1761 measurements were somewhat uncertain, Planman was given the task of calculating a value for the parallax based on all the data received by the academy. This work resulted in values between 8.2″ and 8.7″. As a preparation for the transit in 1769, Planman developed a new method to calculate the parallax, and his own observations in 1769 were considered among the best in Europe. He now found the parallax to be 8.5″. Planman participated in discussions concerning the possible existence of an atmosphere on Venus and also on the much-debated issue of the reliability of the observations carried out by **Miska Höll** in northern Norway (Vardöhus).

By making an observational effort great enough to command the attention of all of Europe, and by giving Planman the main responsibility of handling its observational data, the Academy of Sciences created a platform for Planman that for a few years made him an international authority on the important question of the solar parallax. Otherwise his scientific life was uneventful.

Sven Widmalm

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Plaskett, Harry Hemley

Born **Toronto, Ontario, Canada, 5 July 1893**
Died **Oxford, England, 26 January 1980**

Harry Plaskett made observational and theoretical contributions to the understanding of stellar atmospheres and solar physics, especially through studies of spectral line formation, solar granulation, and the recognition of large-scale mass movements on the Sun's surface. Son of **John Plaskett** and Rebecca Hemley, Plaskett graduated from Ottawa Collegiate School before enrolling at the University of Toronto, where he was awarded his B.A. degree in 1916. During World War I, Plaskett served in the Canadian Field Artillery and rose to first lieutenant among his brigade in France. Afterward, he spent a year at Imperial College, London, in the laboratory of spectroscopist **Alfred Fowler**.

Returning to his native land, Plaskett spent eight years (1919–1927) as a research astronomer at the newly established Dominion Astrophysical Observatory in Victoria, British Columbia, where his father was director. At the time, its 72-in. reflector was the second largest telescope in the world. In 1921, Plaskett married Edith Alice Smith; the couple had two children.

Plaskett was then called to Harvard University (1928–1932), where he served as lecturer, associate professor, and professor of astrophysics. In 1932, Plaskett was chosen as the Savilian Professor of Astronomy at Oxford University, a post that he retained until his retirement in 1960. At Oxford University, he built up a "school" of solar physics that produced a long line of research students. Plaskett had two solar telescopes with spectrographs constructed there, and campaigned (starting in 1946) for a large, modern reflecting telescope in the British Isles. This ambition was realized (after his retirement) with the completion of the Isaac Newton telescope at Herstmonceux in 1967.

Plaskett's research involved analysis of the Sun and stars by means of spectroscopy and spectrophotometry. He was the first to identify four lines of ionized helium in the spectra of O-type stars and deduced their corresponding temperatures of excitation, according to the ionization theory of **Meghnad Saha**. This work led to a new understanding and classification of these very hot stars. Plaskett likewise measured the absorption profiles of the so called magnesium "b" lines in the solar spectrum, as a function of their position on the Sun's disk. These measurements constituted the first practical tests of the relative strengths of scattering versus absorption in the Sun's atmosphere and significantly improved the theory of spectral line formation. Plaskett's detailed study of the phenomenon of solar granulation provided convincing evidence that these small-scale structures were manifestations of Bénard convection cells arising in the photosphere's outer layers. Finally, Plaskett's studies of the Sun's rotation led to his announcement of large-scale velocity fields and especially meridional currents on its surface. He recognized the importance of hydrodynamic considerations to the explanation of such motions, which served as a precursor to later work in solar oscillations and helioseismology.

Plaskett was elected a fellow of the Royal Society of London, and served as secretary (1937–1940) and president (1945–1947) of the Royal Astronomical Society [RAS]. Like his father, Plaskett was awarded the Gold Medal of the RAS (1963) and delivered the Halley Lecture at Oxford University (1965). From 1932 to 1935, he served as president of the International Astronomical Union's [IAU] commission on spectrophotometry. Saint Andrews University conferred an honorary doctorate upon him (1961).

Jordan D. Marché, II

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Plaskett, John Stanley

Born **Hickson, (Ontario, Canada), 17 November 1865**
Died **Esquimalt, British Columbia, Canada, 17 October 1941**

Canadian astronomer John Plaskett is probably best remembered for his role in the establishment of the Dominion Astrophysical Observatory and the building of its 72-in. telescope, briefly the largest in the world. But he also showed (together with **Otto Struve**) that the material that produces stationary absorption lines in the spectra of spectroscopic binaries is truly interstellar and not just circumstellar.

Plaskett was one of a number of children of Ontario farmers Joseph and Annie P. Plaskett, and his father's death when he was only 16 forced him to defer his own education until some of the younger children had been taken care of. He married Rebecca Hope Hemley in 1892, and the elder of their two sons, **Harry Plaskett**, followed in his father's footsteps, eventually becoming Savillian Professor of Astronomy at Oxford University. Trained as a mechanic, John Plaskett acquired some engineering experience in Ontario and Schenectady, New York, USA, and entered the University of Toronto as an assistant to the professor of physics and as a mature student, earning his BA in physics and mathematics in 1899 at the age of 33. He was hired initially at the Dominion Observatory in Ottawa primarily as Mechanical Superintendent, but immediately set to work to establish an astrophysics department, install a number of new instruments, and initiate several new research programs, including solar rotation and radial–velocity measurements of stars.

Plaskett and **William King**, by then director of the Dominion Observatory at Ottawa, soon became dissatisfied with the 15-in. refractor available to them and set out to persuade the Canadian government to fund a 72-in. reflector, somewhat modeled on the Mount Wilson 60-in. telescope, but with innovations of Plaskett's own (like the central hole in the primary mirror for the Cassegrain focus) adopted in later large reflectors. They succeeded by 1913, and a 72-in. reflector was ordered from Warner and Swasey. Plaskett became the founding superintendent (later director) of the Dominion Astrophysical Observatory in Victoria, British Columbia, retiring in 1935, but continuing to serve as a consultant on astronomical instrumentation, particularly for the McDonald Observatory 82-in. telescope, until his death.

Plaskett's leadership had a major role in the development of Canadian excellence in the measurement of stellar velocities and their interpretation. His own work included collaboration with Joseph Pearce on radial velocities of hot, bright stars, which confirmed the work of **Bertil Lindblad** and **Jan Oort** on the rotation of the Milky Way. The investigations with Struve showed, first, that there is gas that is truly interstellar and, second, that it shares the rotation of the galactic stellar system. He was part of the International Astronomical Union commissions on variable stars, stellar classification, and radial velocities, reflecting the unusual breadth of his accomplishments. Plaskett's 1939 drawing of the Milky Way, making clear the relationships among the disk, bulge, halo, and globular clusters is widely reproduced even now.

Plaskett received the Gold Medal of the Royal Astronomical Society, of which he was a fellow, the Rumford Medal of the American Academy of Arts and Science, the Henry Draper Medal of the National Academy of Science, and the Bruce Medal of the Astronomical Society of the Pacific. He was active in the Royal Astronomical Society of Canada and the American Astronomical Society and was a fellow of the Royal Society of Canada and a recipient of its Flavelle Medal. Plaskett received honorary degrees from Toronto, Pittsburgh, British Columbia, McGill, and Queen's universities.

Richard A. Jarrell

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Platevoet, Petrus

➔ **Plancius, Petrus**

Plato

Born **Athens, (Greece), *circa* 428 BCE**
Died **Athens, (Greece), 348/347 BCE**

Plato's astronomy, though never systematized like that of **Eudoxus** or **Aristotle**, continued to influence readers for millennia, through the beauty and coherence of his images and myths.

Plato was born as Aristocles to Ariston and Perictionê, in one of the wealthiest Athenian families, descended from Solon's brother through his mother. He had two older brothers, Glaucôn and Adeimantos, a sister Potonê, and a younger half-brother Antiphôn. Well-educated, Plato in his early 20s came under the influence of Socrates, upon whose execution he left Athens, traveling especially to south Italy and Syracuse. He returned to Athens around 390 or 385 BCE and founded his school in the grove sacred to the hero Akademos. In the 360s BCE Plato again visited Syracuse twice, vainly attempting to teach philosophy to its tyrant Dionysios II. He was unmarried but well loved by his students.

The pervasive dramatic irony of his dialogs, his own express preference for probable accounts, plus millennia-deep scholarship continue to challenge Plato's readers. Certain ideas recur, and may rather confidently be attributed to Plato (not just to characters in the dialogs), but many details may simply be decorative.

Plato discusses astronomy in six dialogs – *Phaedo*, *Republic* (books 7 and 10), *Politicus*, *Timaeus*, *Laws* (books 7 and 12), and *Epinomis* – composed in about that order over a generation. The first three weave astronomy into myth, and all six show a steadily growing appreciation of astronomy. Plato always sought to reveal cosmic design, penetrate phenomena to hidden mathematical reality, and inspire students to contemplate higher truths. Thus, and also because contemporary celestial observations eluded any coherent account, Plato preferred theory over observation.

The 6th-century commentator **Simplicius** reported that **Sosigenes** in the 2nd century quoted **Eudemus** (in the generation after Plato) as saying that Plato's astronomical program was to find regular circular motions of the planets to explain their apparent irregular motions. **Geminus** attributed that program to the

Pythagoreans, who said that even in human affairs, noble men do not alter speed or course, so one must hypothesize celestial uniformity, while **Plutarch** claimed that Plato saved astronomy from reproach by subordinating natural laws to divine principles.

In the *Phaedo*, equilibrium holds the spherical Earth centered in the spherical heaven. Earth is very large, with dimples filled by water, mist, and air, in which people gather like ants around frog ponds; atop the highest peaks lies Earth's true surface exposed to the surrounding bright, clear *aithêr*, through which the stars move.

In the *Republic*, Plato first insists on the utility of astronomy, then its importance in education: The proper goal of astronomical study is to direct the mind *via* theoretical exercise away from the mutable world to the eternal world of truth, just as number and geometry do, and music should. A mythic celestial mechanics completes the *Republic*, in which the whole *kosmos* is a spindle (hung from a rainbow-hued pillar of light), its whorl formed of eight nested whorls, representing the fixed stars and the seven "wanderers" (*planetai*). The outermost whorl, broad and "spangled" with stars, rotates the same as the spindle itself; the seven inner whorls revolve gently in the opposite direction. The eighth (innermost) lunar whorl moves the fastest, illuminated by the next (seventh) and brightest solar whorl. That and the next two (the sixth Venus and fifth Mercury) all move together, with the next greatest swiftness, and so on in descending order out to the second (Saturn). The third (Jupiter) is the whitest – Venus is almost as white, and the fourth (Mars) is ruddy and "recycling" (probably because although Jupiter and Saturn retrograde about once per year, and Venus and Mercury follow the Sun, Mars traverses more than a full circuit of the zodiac between retrogradations). This planetary order – Moon, Sun, Venus, Mercury, Mars, Jupiter, and Saturn outermost – persists in later works. Each whorl has upon it a Seirên singing a single tone, all eight in harmony. The spindle lies in the lap of the goddess Necessity, around whom sit the three Fates: Clotho turning the outer whorl, Atropos turning the seven inner whorls, and Lachesis playing with both. (Plato omits planetary names, and the well-known zodiacal inclination; no one has convincingly explained the whorl-widths – outermost widest, then Venus, Mars, Moon, Sun, Mercury, Jupiter, and Saturn narrowest.)

The myth in the *Politicus* tells that the revolution of the whole Universe affects the course of earthly events, and alters its direction at great intervals. Plato proposed that time is created by the rotation of the *kosmos*, and that when the *kosmos* reverses, so too time reverses in its course.

The *Timaeus* gives a different model, not physical but fundamentally mathematical and deeply religious. The whole divinely ordered *kosmos* is a living spinning spherical creature pervaded by soul. The world-soul contributes to a band, half the length of which, called the "Same," forms the celestial equator moving all the fixed stars with the same motion, while the other half, called the "Other," being divided lengthwise into seven parts, corresponds in a way never completely described to a pair of interleaved geometric series 1, 2, 3, 4, 8, 9, 27, and to the seven planets. Venus and Mercury remain close to the Sun, due to an otherwise unspecified "contrary power." Each planet has its own soul, the cause of its unique motion, and is thereby an "instrument of time." Mere mortals do not understand their motions and periods, but all planets together completing their cycles marks a "perfect" year of the *kosmos*, whose value scholars have spilt much ink vainly computing. Each fixed star is spherical, with a soul whose motion is axial rotation. The Earth herself is wound round the *kosmic* pole, and by resisting the rotation of the whole (unlike the planets) remains the unmoved "guardian of day and night." The *Timaeus*, with its theory of matter founded on the Platonic solids, provided a geometric cosmological model that carried an enormous influence through the time of the Renaissance.

In the *Laws*, astronomy is considered to be useful (for better regulation of the civic calendar), just as arithmetic and surveying are otherwise useful, as well as for mental exercise and training. But the members of the all-powerful Nocturnal Council must study astronomy to learn the primacy in time of soul and the order and divinity of the stars, for only such men are fit for such high rank. True astronomical education will inculcate deep faith, rather than the disbelief caused by the soulless astronomy of mere bodies of stone. (Plato here alluded to **Anaxagoras** and **Democritus**.) Indeed, it is only by asserting that the planets do not truly wander that the wise and devout man may validly study astronomy without committing blasphemy, because the Sun and all stars are ensouled and self-moved.

All ancient philosophers accepted the deeply Platonic *Epinomis*, but some modern scholars have denied his authorship. It argues that astronomy provides the best education for statesmen, and that the celestial bodies are worship-worthy beings through whom we learned number. The stars are fiery-bodied living beings, proven very large, and the Sun "leads" Mercury and Venus.

Plato's world-soul in harmony with all parts of the Universe offered a benign and humanocentric *kosmos*, whose appeal only Epicureans sought to resist before the modern period. Plato's approval of the musical harmony of the stars (which he may have intended as decoration, not definition), and his belief that the planets were divinities worthy of worship, ensured that astrology would be hard to resist, but his insistence that astronomy, with mathematics and music, were the highest studies of which the human mind is capable ensured their survival across centuries when little else did.

Paul Keyser

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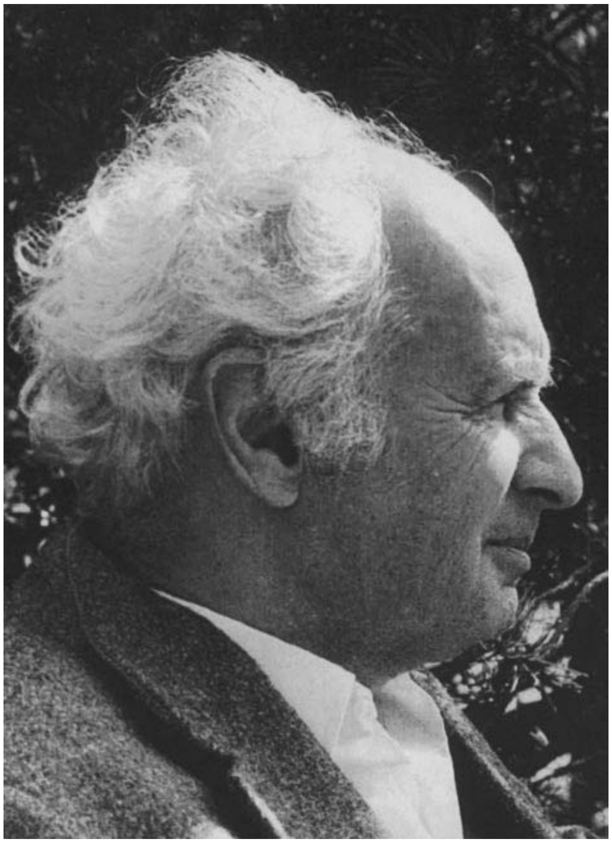
Plaut, Lukas

Born **Kumamoto, Japan, 5 June 1910**
Died **Haren, the Netherlands, 4 October 1984**

Lukas Plaut investigated the intrinsic properties and space distribution of variable stars and eclipsing binaries. He was one of the identical twins born to Joseph Plaut and Katharina Lewy. Plaut received his primary education in Japan and at the Real-Gymnasium of München, Germany



(1925–1929), and attended the Friedrich Wilhelm University in Berlin from 1929 until spring 1933, where he studied variable star astronomy with **Paul Guthnick** at Babelsberg Observatory. Because of his Jewish parentage, Plaut was expelled from the observatory in April 1933, and so he moved to Leiden Observatory in the Netherlands, then under the directorship of **Willem de Sitter**. Here he earned a bachelor's degree (1936), a master's degree (1938), and a doctorate in 1939, with thesis on photographic photometry of two variable stars, guided by **Ejnar Herzsprung**. Occupation of the Netherlands by the German army in 1940 forced Plaut to move first to Groningen (the Kapteyn Laboratory, followed by a modest teaching job), then to a labor camp, and finally to the concentration camp in Fürstenau, Germany.

After liberation of the Netherlands, Plaut returned to Groningen, as a member of the staff of the Kapteyn Laboratory (1945–1964) and as professor of astronomy (1964–1975). There he carried out the work that led to two impressive publications. One, in 1950, was a critical compilation of the orbital elements of 117 eclipsing binaries. The next one, in 1953, was based on the compilation. It presented a thorough discussion of the frequency distribution of the orbital elements (*Groningen Publications* Numbers 54 and 55).

In 1953, at a conference on coordination of galactic research (published as International Astronomical Union Symposium Number 1, 1955), **Walter Baade** proposed a large, systematic survey of faint variable stars of the RR Lyrae type in order to explore the stellar population in the interior regions of the Galaxy, and to arrive at an improved estimate of the distance of the galactic center. Plaut undertook the execution of the program at the Kapteyn Laboratory, which came to be known as the Groningen–Palomar survey of faint variable stars. For four areas at low and intermediate latitudes, carefully chosen in consultation with Baade, Plaut collected long series of photographic plates with the Palomar Schmidt telescope from 1956 to 1959. The variables were detected with an instrument specially designed at the Kapteyn Laboratory by J. Borgman, based on the principle of eliminating all nonvariable stars in the field by combining a negative and a positive photographic image. Observational data and provisional analyses of the about 2,500 variables detected were published by Plaut in the years 1966–1973. The final outcome of this impressive project was the joint paper by Plaut and **Jan Oort**, dealing with the determination of the distance of the galactic center – 8.7 kiloparsecs – and the space distribution of the various types of variable stars in the region within 5 kiloparsecs from the galactic center.

After retirement, Plaut attempted to continue research, but the effects of the persecution and humiliation he had undergone between 1933 and 1945, led to mental disturbances and gradual lack of contact with the world.

A nearly complete set of Plaut's publications, as well as many of his notebooks used for lectures and research, is kept in the archives of the Kapteyn Institute of Groningen University.

Adriaan Blaauw

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Pliny the Elder

Born **Novum Comum, Gallia Cisalpina, (Como, Italy), 22 or 23**
Died **Stabiae, (Campania, Italy), August 79**

Pliny's *Natural History* described the known state of astronomy and astrology, and was influential for 1,000 years or more.

Pliny's *Natural History*, in 37 volumes, contained, he wrote, "twenty thousand noteworthy facts obtained from one hundred authors … with a great number of other facts in addition that were either ignored by our predecessors or have been discovered by subsequent experience." This composition was Pliny's last, for the natural spectacles that he so admired led him to his death: As commander of the Imperial Fleet at Misenum, he had set sail partly for a closer look at the eruption of Mount Vesuvius, and partly to rescue those stranded by the same eruption. Landing at Stabiae, he judged the situation safe enough to bathe, sup, and snore through the night. But just before dawn, Pliny was awakened for immediate evacuation. The exertion and excitement must have proven too much for the corpulent, unfit asthmatic: Arriving at the beach, he fell down and died, apparently from a heart attack.

Pliny was born in an equestrian family – whose status gave access to a public service career. His sister married a wealthy landowner and bore a son – Pliny the Younger – whom the Elder adopted as his own. Apart from the Elder's own writings (only his *Natural History* is extant), the Younger's letters to the historian Tacitus supply our best observations of Pliny's life, death, and person.

Before the *Natural History*, Pliny had composed at least six other works on several topics – grammar, oratory, history, cavalry technique, and a biography – and had followed a distinguished military and government career. He was well traveled and a close observer of all that went on around him.

Pliny shunned most of the material luxuries common to his time, preferring instead to study and write, and to quietly enjoy natural phenomena. His effort was to become educated in everything, as he saw the Greeks to be, but he noted that the Greek mastery of individual subjects had produced no single work summarizing the whole. So Pliny took this task – the unification of the whole *enkuklios paideia*, "all-encompassing learning" – upon himself.

Pliny's survey became an encyclopedia, the *Natural History*. Its coverage is necessarily superficial and in many places wrong, but it is neither sterile nor wholly uncritical: Pliny stated and judged his sources, often expressing wonder, surprise, or doubt. Setting aside the introductory and bibliographical Book I, the *Natural History* opens with astronomy and cosmology in Book II. Pliny began with a generally Stoic overview of the cosmos, earlier investigations into its nature and size, and its arrangement. Although he gave some relative dimensions of its parts, he dismissed attempts upon its overall dimensions as "madness, downright madness." Eliminating theology from the study of nature, Pliny rejected inquiry into God's existence, shape, and form as "a mark of human weakness." Divinity, he retorted, belongs to that which *obviously* governs the rest of the cosmos: the Sun.

Having set theology apart from astronomy, Pliny went on to describe planetary motion and eclipses quantitatively, giving periodicities and ranges of motion in coordinate systems that are unfortunately inconsistent and unspecified. He stated the order of the geocentric planetary orbits, and the interplanetary spacings according to Pythagorean harmonic theory, which he immediately rejected as "a refinement more entertaining than convincing." But the planetary order was justified by its ability to explain, at least qualitatively, the planetary elongations and speed variations. Planetary motions are governed by orbital curvature and solar rays, the Sun clearly being, Pliny observed, the governing power of the cosmos, controlling the planets from their midst and the Earth from above.

Pliny's treatment of astrology is noteworthy for its detail and balance: While Pliny certainly believed in astrological influence, he was unhesitant in denouncing astrologers. He enumerated biological evidence for celestial influence: Certain plants bloom or move according to the Sun. "Persistent research" showed that the Moon influences shellfish growth, ant activity, and eye diseases in cattle. Storms can be caused by the stars, and winds by the Sun, and the various winds arise on dates measured by stellar risings and settings. Despite this, Pliny considered astrologers mistaken in assigning individual stars to individual people, and he thought it implausible to attribute chance to stellar influence: Because stellar motions are predetermined, such "chance" would not be chance at all.

Why all this attention to astronomy and astrology, in a culture that valued practical engineering and government so much more than theoretical science? Pliny gave two reasons: to combat superstitious fears of gods and nature, and because astronomy and astrology genuinely do influence life, especially through agriculture. Pliny devoted a book to astronomical farming calendars, giving content from the Greeks and Babylonians, noting their disagreements on astronomy and also on what farmers should do at different times of the year. Despite these disagreements he considered them useful, given the absence of any simpler, nonastronomical system.

The shallowness of Pliny's *Natural History* – hardly avoidable in any single-author encyclopedia – did not prevent its long-lived influence on the astronomy of several important medieval writers, particularly **Martianus Capella** and **Bede**, and hence on all who studied their works in subsequent centuries. This tradition perpetuated Pliny's planetary data and, perhaps more importantly, his doctrine that solar rays govern planetary movement. Overall, Pliny's *Natural History* became widely used for general education. Around the 12th century, his solar-ray doctrine ceded ground to element-based theories of Aristotelian and Platonist origin. The absence of epicycles in Pliny's planetary system inspired further rejection of his astronomy in the Renaissance, compounded by growing awareness of his unreliability more generally. In recent decades he is read as representative of knowledge not in our day, but in his own.

The rest of Pliny's works are lost. They include a work *De iaculatione equestri* (On horseback javelin–throwing); the 20-volume *Bella Gemaniae* (German Wars); the 6-volume *Studiosi* on oratorial training; the 8-volume grammar, *Dubius sermo*; a two-volume biography of his patron, *De vita Pomponi Secundo*; and 30 volumes on the *History of Rome*.

Alistair Kwan

Alternate name

Plinius secundus

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Plinius Secundus

➜ **Pliny the Elder**

Ploti Ferrariensis

➜ **Novara, Domenico Maria da**

Plummer, Henry Crozier Keating

Born **Oxford, England, 24 October 1875**
Died **Oxford, England, 30 September 1946**

Henry Plummer, who served as Andrews Professor of Astronomy and Astronomer Royal of Ireland, conducted valuable research on variable stars and stellar motions. He is commemorated in Plummer models for the distribution of stars in globular clusters and other spheroidal systems. Plummer was the eldest son of William Edward Plummer, an astronomer and then senior assistant at the Oxford University Observatory, and Sara Crozier. The elder Plummer later became director of the Observatory of the Mersey Docks and Harbour Board and reader in astronomy at the University of Liverpool. Henry Plummer's education began at Saint Edmund's School, Oxford, and continued at Hertford College under a scholarship. He took first class honors in Mathematical Moderations and Finals, as well as the Open Mathematical Scholarship and a second class in Final Honours School of Natural Science (physics). Plummer then spent a year as a lecturer in mathematics at Owen's College, Manchester, before returning to Oxford in 1900 to spend a year as assistant demonstrator at the Clarendon Laboratory.

In 1901, Plummer accepted the position of second assistant in the University Observatory under the directorship of **Herbert Turner**. By this time, he had published several papers on astronomy and been elected a fellow of the Royal Astronomical Society [RAS]. Despite its low salary, the post offered him his first opportunity to work professionally in astronomy. With the exception of a year spent as a fellow at the Lick Observatory (1907), where he worked on spectroscopy, Plummer remained at the University Observatory until 1912. There, he coordinated its participation in the International *Carte du Ciel* Astrographic Chart and Catalogue, and investigated systematic errors in the positions of images on photographic plates. During this time, Plummer also produced a number of papers on other topics.

In 1912, Plummer succeeded **Edmund Whittaker** as Andrews Professor of Astronomy at the University of Dublin and Astronomer Royal of Ireland. He was placed in charge of Dunsink Observatory, which, owing to poor funding, could make only one serious contribution to astronomy, that being the observations of variable stars. But the observatory's location in the secluded countryside was not conducive to Plummer's lifestyle; he was a bachelor and was described as a "townsman." Added to that were the political troubles that arose in Ireland after the end of World War I. As a result, he faced the very difficult decision of giving up his career in astronomy in 1921 in favor of returning to England as chair of mathematics at the Artillery College, Woolwich (later the Military College of Science), a post he held until his retirement in 1940.

Plummer's responsibilities at the military college left him little time for astronomy. Nonetheless, he remained tied to the astronomical community and while at Woolwich managed to publish about a dozen astronomical papers. Plummer regularly attended meetings of the RAS and was elected the Society's vice president (1936–1937) and president (1939–1941). He had been elected a fellow of the Royal Society in 1920, just prior to his departure from Ireland. In 1924, Plummer broke his lengthy solitude by marrying his longtime friend Beatrice Howard. The couple did not have any children. In 1940, upon his retirement, he and Beatrice returned to Oxford where, in 1942, he gave the Halley Lecture. Beatrice died in the spring of 1946, from which Plummer never fully recovered.

Plummer's contributions to astronomy were many and varied. His first published work describes a graphical method of solving Kepler's equation. A scan of Plummer's early papers reveals topics as varied as using projective geometry to solve binary star orbits, measuring occultations of stars by the Moon, compensating for errors in a siderostat, and studying images formed by parabolic mirrors. Two of his papers on comet 2P/Encke discredited the then-current model of solar-radiation pressure as the cause of its anomalous acceleration. Plummer's work on the *Astrographic Catalogue* not only flexed his mathematical muscle but also displayed his skill with astronomical equipment. His most remembered text, *An Introductory Treatise on Dynamical Astronomy* (1918), was a significant contribution to celestial mechanics and planetary theory. Plummer returned to this subject again in 1932 after learning of numerical investigations carried out at the Copenhagen Observatory.

By far Plummer's most prolific areas of research were studies of variable stars and of stellar motions. At Dunsink Observatory, Plummer and his assistant, Charles Martin, conducted photometric observations of variable stars, in conjunction with measurements of their radial velocities. Plummer showed that eight of those stars, including ζ Geminorum, could not be spectroscopic binaries, as had been assumed, because their atmospheres displayed radial pulsations. This was among the first evidence gathered for the theory of pulsations in classical Cepheid variables, a theory developed more fully by **Arthur Eddington**.

In 1911, Plummer derived an expression for the spatial distribution of stars in globular clusters and their apparent two-dimensional representations on photographic plates. From this relationship, he concluded that most clusters had condensed from primitive spherical nebulae while maintaining convective equilibrium. Plummer also began a lengthy study of the parallaxes of B- and A-type stars in the Milky Way. His results showed a relatively simple way to estimate the parallax of a star from known values of its proper motion and radial velocity. More importantly, he emphasized a distinction between the two principal velocity fields of stars in the Milky Way system: (1) those that are moving parallel to the plane of the galactic disk, and (2) those that exhibit a more spherical (or random) distribution. After Plummer's death, these two dynamical systems were recognized as related to the two stellar populations defined by **Walter Baade**, for which any model of galaxy formation must account.

Plummer was also very interested in the history of science. In 1939, he was asked by the Royal Society to edit the complete works of **Isaac Newton** before the tercentenary of Newton's birth (1942). Unfortunately, World War II put most of the project on hold, and it remained incomplete on Plummer's death. (It was eventually completed by the Society.) At the Society's triple centenary celebration of Newton, **Galileo Galilei**, and **Edmond Halley** on 9 October 1942, Plummer delivered the address on Newton. His 1942 Halley Lecture was entitled, "Halley's Comet and Its Importance."

Ian T. Durham

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Plutarch

Born **Chaironeia, Bœotia, (Greece), *circa* 45**
Died ***circa* 125**

Though most famous for his biographies, Plutarch also wrote a dialog on the Moon, in which the participants discuss the Moon's appearance and possible habitability, and how it is able to remain in orbit. Plutarch is best known as a biographer, but none of his contemporaries seems to have written a biography about him – nearly all that we know about Plutarch comes from clues in his own writings. Plutarch lived in a time of peace and contemplation, and seems to have spent most of his life in or near his beloved hometown. He did, though, manage to travel widely: He studied at Athens under the Peripatetic philosopher Ammonius of Lamptrae. He served his town as building commissioner and archon, and participated in a diplomatic mission to the Roman proconsul. Plutarch's travels took him throughout Greece, and he ventured as far as Alexandria, Asia Minor, north Italy, and Rome. In Rome, Plutarch spent about 15 years attending to matters of state, but also lectured on philosophy, probably in Greek, for he never found time to learn Latin. His social circle embraced Rome's most prominent, among whom Mestrius Florus gave him Roman citizenship with an official Roman name, Mestrius Plutarchus. On returning from Rome, Plutarch became a priest at Delphi (near Chaironeia), where he apparently remained until the end of his life. Two inscriptions there testify to his presence: One under a statue of Hadrian, and one under a statue of Plutarch himself. Though both statues have been destroyed, the inscriptions, plus a third inscription at Chaironeia, indicate the esteem in which Plutarch was held.

Plutarch's fame originates in his abundant and eloquent writings. Most famous is the *Lives of Famous Men*, a collection of parallel biographies that contrasts the virtues and vices of Greece's and Rome's prominent public figures. Less famous are 78 essays collected as the *Moralia*, of which about 12 are thought to be written by other authors. The *Moralia* are, as their name suggests, mostly of moral tone. Some of them, such as the dialog *De facie in orbe lunae apparet* (on the Moon's face) present scientific topics for nontechnical readers.

In *De facie*, six interlocutors discuss what might lie behind the Moon's uneven appearance. The discussion presents viewpoints from several Greek schools – including the Academics, Epicureans, Peripatetics, and Stoics – and considers astronomy, cosmology, geography, and the optics of reflection. The interlocutors weigh the several philosophical viewpoints against each other for physical plausibility, after which one of the interlocutors summarily concludes that the face is due to topographical features in its Earth-like terrain. The conversation then turns to whether the Moon might be so Earth-like as to be habitable, what kinds of plants and animals might live there, and why they would not fall off. There is also some discussion of whether the lunar beings are terrestrial souls who, by being either deceased or not yet born, lack bodies. Understandably, in debates on extraterrestrial life and the plurality of worlds, *De facie* was routinely cited well into early modernity.

Other highlights of *De facie* include discussion on how the heavy Moon can remain aloft. One proposed explanation seems tantalizingly close to modern thought: Comparing the Moon's revolutions to a stone whirled in a sling, Plutarch writes, "the moon is saved from falling by its very motion and the rapidity of its revolution … for everything is governed by its natural motion unless it be diverted by something else." There is a description of a total solar eclipse, one of only a few from classical times that mentions stars appearing in the darkness, and perhaps the only classical description of the temperature drop and the solar corona.

Along with the rest of his writings, *De facie* remained influential for centuries after Plutarch wrote it. It has been copied, edited, and emulated by many with scientific motives, the last of whom included **Johannes Kepler**. Kepler was strongly attracted to Plutarch's discussion on lunar habitation: *De facie* is an important influence behind Kepler's *Somnium* on lunar astronomy. Some of Plutarch's other writings include astronomical material, too, in particular his expansions on **Aratus**'s *Phænomena* and a commentary on **Hesiod**'s *Works and Days*. These have received less attention than *De facie*, which, since Kepler's day, has received little attention indeed.

Alistair Kwan

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Poczobut, Marcin [Martin Poczobutt]

Born **Slomiank, (Lithuania), 30 October 1728**
Died **Daugavpils, (Latvia), 17 November 1810**

Lithuanian astronomer Marcin Poczobut directed the astronomical observatory at Vilnius University and contributed to the refinement of cartography in Eastern Europe. He was born in the Gardinas region of Lithuania. His father, Kazimier Odlanicki Poczobut, came from a noble family once promoted to *bojar* by King Sigismund I in 1536. His mother was Helena Hlebowicz.

Poczobut became a Jesuit in 1745 and followed that society's tenets until it was banned in 1773. After his graduation from Vilnius University in 1751, he continued studies of Greek, Latin, and mathematics at Prague University. He studied next in France and Italy from 1761 to 1763, where he acquired much of his knowledge of mathematics and astronomy. Upon returning to his homeland, Poczobut was appointed professor of mathematics and astronomy (1764) and later rector of Vilnius University (1780–1799). As third director of the university's astronomical observatory (1764–1808), he added new instruments, including a sextant of 6-ft. radius (1765) and a mural quadrant of 8-ft. radius (1777). To obtain this equipment, Poczobut traveled to England and France, visiting the Greenwich and Paris observatories.

With the large sextant, Poczobut measured the precise length and width of Vilnius for the first time. In recognition of this work, King Stanislaus II bestowed upon him the title of Royal Astronomer (1767), and likewise honored the observatory. Poczobut made other contributions to geodesy and cartography. He determined the geographic coordinates of some 20 points in Lithuania and Latvia, and together with Jan Sniadecki, submitted a plan of dividing Lithuania, Poland, and White Russia into 400 quadrangles. He directed the work of A. Rostanas, J. Bistrickas, and others. Poczobut also participated in K. Perthes's cartographic work in western Lithuania and Courland (now part of Latvia).

Poczobut conducted regular astronomical observations, the most famous of which involved some 60 precise positions of the planet Mercury, from which **Joseph de Lalande** calculated an improved orbit of the planet. In 1766, Poczobut published a book about eclipses of the Moon, which compared data from the observatories of Paris, Vilnius, Warsaw, Krakow, and London.

In 1777, Poczobut asked the French Academy of Sciences to honor the last Polish monarch, King Stanislaus (Poniatowski) II, with a constellation. For this, he selected a V-shaped group of stars mentioned in **Ptolemy**'s *Almagest* that lay just outside of Ophiuchus. The designation did not last, but Poniatowski's bull may still be found on some older star charts; the bull's head is formed by the stars 67, 68, and 70 Ophiuchi.

For a brief time, Poczobut was a member of the provisional government of Lithuania formed in Vilnius during the 1794 rebellion against the Russians. Along with 18 others, he signed the Proclamation of the Lithuanian Supreme Council on 30 April 1794.

Poczobut exhibited extraordinary interest in the first minor planet, (1) Ceres, discovered in 1801. During his 73rd year, Poczobut reportedly "continued to search for and tirelessly observe this body with such persistence and effort that he lost consciousness several times." After Ceres was designated by the sign of a sickle, Poczobut sang its praises with a Latin distich, translated as: "Whoever taught the sickle to cut the stalks of standing corn/The toothed sickle shall become for you the garland of Ceres."

Ancient Egypt was another subject of Poczobut's fascination. He published two papers on the probable age of the Dendera zodiac, recovered from the temple of Hathor by Napoleon Bonaparte's armies and transported to the Louvre.

In 1808, Poczobut resigned as head of the Vilnius Observatory and moved to a monastery. The Polish poet Adam Mickiewicz mentioned him in his epos, *Pan Tadeusz*. He wrote that Poczobut was a priest and astronomer who had finished his life in peace and silence.

Poczobut was named a Knight of the White Eagle and was a recipient of the Order of Saint Stanislaus. He was elected a member of the Royal Society of London (1769) and a corresponding member of the French Academy of Sciences (1781).

Clifford J. Cunningham

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Poe, Edgar Allan

Born **Boston, Massachusetts, USA, 19 January 1809**
Died **Baltimore, Maryland, USA, 7 October 1849**

Edgar Allan Poe's *Eureka* has gained attention because of its potential affinity with what in the late 20th century emerged as the standard "Big-Bang" cosmology.

Poe was the second child of actors David Poe and Elizabeth Arnold Poe, both of whom died before their son turned three. Poe then became the foster son of Fanny Allan and her husband, John Allan, a businessman in Richmond, Virginia. Although best known as a writer of haunting poems and exquisitely plotted fantastic tales, Poe has gained attention in the history of astronomy for his speculative but seemingly prescient cosmogony, which opened a cosmic narrative unfolding from a singular "primordial particle."

In 1848, a year before his premature death, Poe published *Eureka: A Prose Poem*, dedicated to **Alexander von Humboldt**, German author of the multivolume treatise *Kosmos*. In *Eureka*, Poe sets out "to speak of the physical, metaphysical and mathematical – of the material and spiritual universe – of its essence, its origin, its creation, its present condition and its destiny." While assuming (Newtonian) absolute space, Poe distinguishes "the universe of stars" from "the universe proper," and propounds an intriguing evolutionary account of the former, the sidereal Universe. The plot begins with "a particle absolutely unique, individual, undivided," and it evolves accordingly from that singularity: "From that one particle" are "irradiated spherically – in all directions – to immeasurable but still to definite distances in the previously vacant space – a certain inexpressibly great yet limited number of unimaginably yet not infinitely minute atoms."

Some have seen Poe as pointing toward a solution to Olbers's paradox (Harrison), or even toward the anthropic cosmological principle as an explanation for the large size of the Universe (Cappi). Strictly speaking, Poe's "primordial particle" was speculative, nonscientific, and perhaps merely a curiosity. On a broader historical canvas, however, it stands as a noteworthy mid-19th-century example of the impulse to offer an evolutionary account of cosmic history, and as a perennial example of the longing of the human imagination to tackle questions concerning the physical origin of the Universe.

Dennis Danielson

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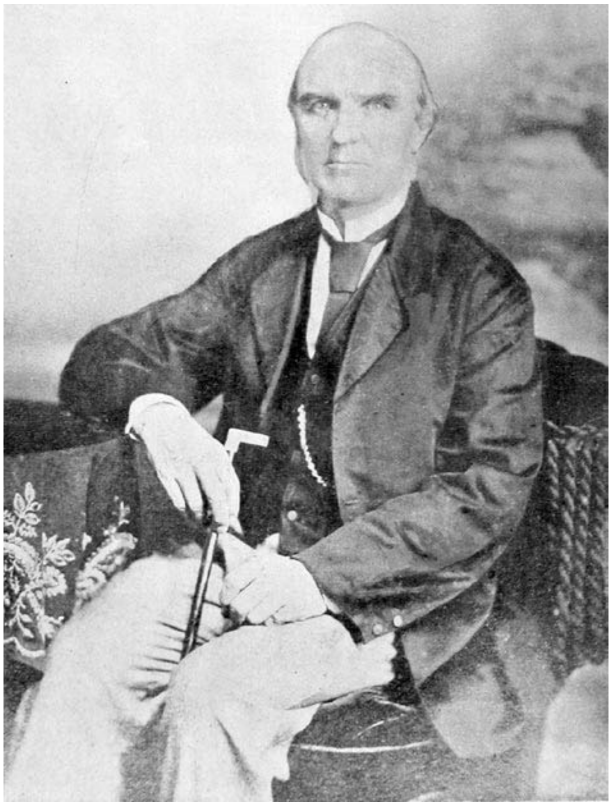
Pogson, Norman Robert

Born **Nottingham, England, 23 March 1829**
Died **Madras, (India), 23 June 1891**



Norman Robert Pogson discovered eight asteroids and 20 variable stars but is usually remembered for his recommendation leading to the adoption of a standard value of the photometric constant, which standardizes the old Greek magnitude system of stellar brightnesses.

Although his father, George Pogson, an established hosiery manufacturer, intended a career in business for his son, Norman developed an early interest in science. It is likely that his mother Sarah's intuitive understanding of this saved him from a Dickensian existence as an apprentice in the textile business. Pogson was twice married, first to Elizabeth Jane Ambrose. They had 11 children. Elizabeth died of cholera in 1869. He then married Edith Louisa Stopford in 1883. She bore him three children. A daughter of his first wife, Elizabeth Isis Pogson, served her father as assistant at the Madras Observatory from 1873 to 1881. She later became Meteorological reporter for Madras. Elizabeth was first proposed for fellowship in the Royal Astronomical Society in 1886, being admitted at last in 1920.

A family friend, **John Hind**, an assistant at George Bishop's South Villa Observatory in London, recommended Pogson's appointment as assistant at South Villa in 1851. Less than a year later he accepted an assistantship at the Radcliffe Observatory, Oxford, under the directorship of **Manuel Johnson**. Pogson's main duty was to make routine observations of stellar positions with the meridian circle, but his enthusiasm was such that he made additional observations even outside the required working hours. Johnson lent Pogson's services to **George Airy** for the Astronomer Royal's famous Harton Colliery experiments to measure the density of the Earth in 1854. Pogson's painstaking attention to detail made a positive impression on the Astronomer Royal. During his Oxford years, Pogson began actively searching for asteroids and monitoring variable stars. The French Academy of Sciences awarded him the Lalande Medal for his discovery of the minor planet (42) Isis in 1856.

That same year Pogson proposed the adoption of a light ratio of 2.512 (the fifth root of 100) for two stars that differ in brightness by one magnitude. The resulting magnitude scale eventually became an international standard after both Harvard and Potsdam observatories adopted it for their photometric programs in the 1870s.

Pogson's desire for more freedom in his astronomical activities brought him into conflict with Johnson. In the mid-1850s he gained the attention of gentleman–scientist John Fiott Lee, who maintained a private observatory at Hartwell House near Aylesbury, Buckinghamshire. Lee offered Pogson the directorship of the Hartwell Observatory, and Pogson accepted. The position provided more freedom of action but was not considered to be of professional standing, a status Pogson ardently desired. On Johnson's death, Pogson applied unsuccessfully for the Radcliffe Observership; a year later, with the support of Airy and Sir **John Herschel**, he was appointed government astronomer at the Madras Observatory in South India.

What first appeared to secure professional recognition for Pogson eventually led to the total eclipse of his career. In a remote location, the Madras Observatory was in disrepair when Pogson arrived, and the astronomer's salary proved inadequate to support his family in India. The government denied him any additional assistance in running the facility, and contemplated its closure more than once during his tenure. Pogson's oversensitive personality did not aid his cause. A quarrel with the Royal Astronomical Society over a planned survey of southern stars soured his relations with the British scientific community. His observations of the solar eclipse of 1868 – he had been one of the first to observe the bright line spectrum in the corona – did not receive due credit because the Indian government authorized the printing of only three copies of his report.

Pogson labored on, embittered by his relations with officialdom and mourning his first wife and eldest son, both of whom died in Madras. He withheld publication of meridian circle observations and telegraphic longitude determinations. Finally, in 1884 a sympathetic governor of Madras, Sir Mountstuart Elphinstone, encouraged Pogson to publish his results. Elphinstone also proposed him for fellowship in the Royal Society, but the application failed. Thereafter, Pogson ceased regular observation, although he remained government astronomer until his death from liver cancer. At the time of his death, he was widely, if mistakenly, considered to have been a scientific nonentity.

Pogson was in fact one of the great visual observers of his time. A pioneer of variable star astronomy, he toiled for many years over an atlas of variables comprising charts of some 60,000 stars. **Edward Pickering** arranged for a grant from the Bruce Fund to support publication of the atlas, but Pogson died before he was able to complete the project. Fragmentary results were finally published in 1908 in the *Memoirs of the Royal Astronomical Society*.

Keith Snedegar

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Poincaré, Jules-Henri

Born **Nancy, Meurthe–et–Moselle, France, 29 April 1854**
Died **Paris, France, 9 July 1912**

The French mathematician and philosopher Henri Poincaré made contributions to a wide range of scientific problems, including many in celestial mechanics. Poincaré came from an eminent French intellectual family. His father was professor of medicine at the University of Nancy, and an uncle inspector-general of roads and bridges in France. His cousin, Raymond Poincaré, was a lawyer, statesman, and president of the French republic during World War I, and his sister married the philosopher Emile Boutroux. Henri Poincaré was happily married to the great granddaughter of the zoologist Etienne Geoffroy Saint-Hilaire.

From infancy, Poincaré experienced bad health, including diphtheria at age five. His motor coordination was poor, he had great difficulty learning to write, and he found drawing impossible. Poincaré was not able to read from a blackboard, but his memory was such that he could memorize mathematical formulae and theorems upon hearing them, and remember the exact contents of books after a single reading.

Poincaré studied at the École Polytechnique and the École Supérieure des Mines (School of Mines), both in Paris. His inability to draw was a problem for a potential engineer, but he revealed himself as a brilliant student and genius in mathematics. After graduating as a mining engineer, Poincaré earned a doctorate in mathematical sciences at the Paris Faculty of Sciences, with a thesis on differential equations. Appointed professor of mathematics at the University of Caen in 1879, he moved to the University of

Paris 2 years later, where he held the chair of experimental physics until his death. Considered the last universalist in mathematics, Poincaré published more than 500 papers and 30 books on nearly all branches of pure and applied mathematics, including theoretical physics and mathematical astronomy.

In 1889, Poincaré received a prize offered by King Oscar II of Sweden and Norway for work on the stability of orbits in the *n*-body problem (in which more than two gravitating point masses mutually interact). This was on the advice of German mathematician Karl Weierstrass, who pointed out that, although Poincaré had not solved the problem in full generality, his results "inaugurated a new era in the history of celestial mechanics." Poincaré developed new mathematical techniques to approach the *n*-body problem and showed that there is no analytical solution already for the case of three bodies: The orbits can have very irregular and chaotic form. Thus Poincaré's work was a predecessor of modern chaos theory as applied, for instance, to the mutual perturbations of the orbits of the outer planets.

Poincaré summarized his research on celestial mechanics in his fundamental work *Les méthodes nouvelles de la méchanique céleste* (three volumes, published 1892–1899) and his more practical *Leçons de méchanique céleste* (1905–1910). He applied the results of his study of the equilibrium of rotating fluid bodies (*Figures d'équilibre d'une masse fluide*) to the problem of the origin of the Solar System (*Leçons dur les hypotheses cosmogonique*). He concluded that the planets could not have formed from rotating bodies that contracted as they cooled (as implied in the hypothesis of **Pierre de Laplace**) because the rotating mass would separate into two distinct, unequal masses. The process may be relavant to the formation of binary stars. Poincaré also applied the method to the rings of Saturn. In 1906, his mathematical investigations of electromagnetism yielded results analogous to those put forward some months earlier by **Albert Einstein** in his special theory of relativity.

Besides his purely scientific work, Poincaré wrote some very accessible books on the philosophy of science and mathematics. These books became very popular and were translated into many languages. For his literary talent, he was elected member of the Académie française in 1908, while he was already member of the Académie des sciences, the Royal Society, and many other academies and scientific societies.

Tim Trachet

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Poisson, Siméon-Denis

Born **Pithiviers, (Loiret), France, 21 June 1781**
Died **Paris, France, 25 April 1840**

Siméon-Denis Poisson's greatest contribution to astronomical and physical theory, the Poisson bracket, was generated by the mathematical development of perturbation calculation for the Solar System. He is also remembered for poisson statistics, appropriate for samples with small numbers of members, as often happens in astronomy.

Poisson came from a modest family background. His father, a former soldier, had purchased a low-ranking administrative post in Pithiviers. In 1817, he married Nancy de Bardi, an orphan born in England to *émigré* parents.

The French Revolution, which Poisson supported enthusiastically, made it possible for him to advance to the presidency of the district. Poisson was guided by his father toward those professions to which access had been made easier by First Republican social legislation. Thus, enrolled in the École Centrale of Fontainebleau, he took advantage of his instruction to obtain first place in the national competitive examination to enter the new École Polytechnique, to which he was admitted in 1798.

At the école, Poisson impressed the eminent **Pierre de Laplace** and his colleague, **Louis Lagrange**, with his intelligence, industriousness, and perspicacity. With formidable mathematical talent and enjoying the steady support of the highly placed Laplace, Poisson advanced rapidly to positions of increasing responsibility and eminence: instructor at the École Polytechnique upon his graduation in 1800; deputy professor in 1802; professor of analysis and mechanics in 1806; astronomer at the Bureau des longitudes in 1808; professor of mathematics at the newly established Faculty of Sciences at the Sorbonne; and culminating in election as member of the physics section of the elite Institut de France in 1812.

J. Heilbron terms the mathematical worldview within which Poisson worked as the first modern "standard model." It interpreted physical law as the operation of weightless, "imponderable" fluids, two each for electricity and magnetism, one for heat, one for light, and one for the newly discovered infrared radiation. These imponderables were believed to operate in a manner analogous to gravity, as inspired by the delicate experiments of Charles-Auguste de Coulomb demonstrating how the attraction between static electrical charges varied, as did gravitational attraction, with the inverse square of their separation. Laplace was the leader of this enterprise and Poisson his outstanding disciple.

In the analysis of perturbations, one may begin with the positions of a number of celestial bodies, all mutually attracting one another gravitationally, along radius vectors. If we call the number of vectors r, their attraction will satisfy r second-order differential equations, which can be written in the generalized coordinates introduced by Lagrange. Whether or not these equations are analytically soluble, the integrals of the set of differential equations depend upon $2r$ arbitrary constants. In a supplement to Book VIII of Laplace's *Mécanique céleste* that appeared in 1808, Lagrange developed the implications of Poisson's observation, reported to the Academy of Sciences early that year, that the $2r$ arbitrary constants must satisfy r physical constraints: Specifically, Lagrange proved that in the presence of a perturbation that forces the arbitrary constants to be treated as functions of time, the derivatives of the desired functions with respect to time are the solutions of a linear system in which the coefficients of the unknowns are independent of time.

Using a mathematical transformation, Poisson, in 1809, then extended and generalized Lagrange's result, modifying the variables so that they retain the same form – the Poisson bracket – even upon the introduction of the perturbation function. In the following decades William Rowan Hamilton and Carl Jacobi used the Poisson bracket as an essential element in their geometric reformulation of the dynamical equations of physics, and in the 1920s, Paul Dirac identified the Poisson bracket as crucial in the mathematical structure of Werner Heisenberg's novel quantum mechanics. It is of interest to note that Poisson also anticipated the δ-function made famous by Dirac's employment of it.

Poisson also attempted to complete a didactic presentation of the "standard model" in a series of clearly written and widely read textbooks. He assumed the positions of examiner of graduating students at the École Militaire in 1815 and that of the École Polytechnique the following year. He was named to the Royal Council of the university, the highest educational consultative body in the restored monarchy in 1820.

Another work of Poisson that is of great significance to astronomy is his *Recherches sur le mouvement des projectiles dans l'air* (1839), which first discussed in print the importance of a term, discovered by his doctoral student Gustave Gaspard de Coriolis, to correct for the deviations from the law of motion arising from a rotating frame of reference. A decade later this work inspired the striking experiment of the Foucault pendulum, which demonstrates in a dramatic way the Earth's rotation on its axis. Poisson, however, chose not to mention Coriolis's name. By the time of his death, Poisson had published some 300 papers and books.

Poisson was elected foreign associate of the Royal Society of London in 1818 (and received its Copley Medal in 1832); he was a member of virtually all the academies of the day from Boston to Saint Petersburg. That this adherent of the First Republic was honored by the empire and made a Peer of France by the Orleanist monarchy in 1837 is evidence of his political discretion.

Michael Meo

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Pollio, Marcus

❯ **Vitruvius, Marcus**

Pond, John

Born **London, England, 1767**
Died **Blackheath, (London), England, 7 September 1836**

John Pond, England's sixth Astronomer Royal, raised the observing program at the Royal Greenwich Observatory to a new standard of excellence. The son of a well-to-do retired businessman, Pond developed an interest in astronomical observations while being tutored at home by **William Wales**, who had served as astronomer and conavigator to Cook on the second voyage of the *HMS Resolution*. As a teenager Pond detected errors in Greenwich observations. After enrolling at age 16 as a chemistry student at Trinity College, Cambridge, he withdrew before completing his degree because of ill health. Sent abroad to warmer climates to recuperate, Pond made astronomical observations during his travels.

Upon his return to England in 1798, Pond began making astronomical observations from his private observatory near Bristol, at Westbury in Somerset, with an altazimuth refractor equipped with 2½-ft.-diameter circles designed by Edward Troughton, one of England's leading makers of scientific and astronomical instruments. Pond's work proved that the Greenwich Observatory quadrant had been deformed by age. This work, published in the *Philosophical Transactions of the Royal Society* in 1806, led to his election the following year as a fellow of the society as well as the institution of a program by **Neville Maskelyne**, the fifth Astronomer Royal, to upgrade Greenwich's instrumentation.

Following marriage in 1807, Pond established his home in London, where he continued working in astronomy using excellent instruments whose construction was supervised by Troughton. After his appointment in 1811 as Astronomer Royal when Maskelyne retired, Pond devoted most of the next quarter-century to upgrading the equipment, staff, and procedures of the Greenwich Observatory. Troughton had designed a new mural circle, ordered by Maskelyne, which enabled Pond to obtain the data for his 1813 catalog of the north-polar distances of 84 stars. The observations made with the circle in 1813/1814 also enabled Pond to challenge the accuracy of claims by **John Brinkley**, the first director of the Dublin Observatory, to have detected stellar parallax of a number of fixed stars. Not only was Pond's assertion that effects of parallax could not be detected with contemporary instruments later proved right, but also his challenge helped stimulate **Friedrich Bessel**'s subsequent successful work in that field. During Pond's tenure, Troughton designed for the Greenwich Observatory a new transit instrument and a 25-ft. zenith telescope, which were erected in 1816 and 1833, respectively. Before ill health forced Pond to retire in 1835, he completed his crowning achievement, a catalog of 1,113 stars, observed more precisely than ever before, which was published in 1833. He is best remembered, however, for beginning the fundamental modernization of the national observatory, a task carried on with zeal by his successor **George Airy**, who regarded Pond as the "principal improver of modern practical astronomy."

Naomi Pasachoff and *Jay M. Pasachoff*

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Pons, Jean-Louis

Born **Peyre, (Hautes-Alpes), France, 24 December 1761**
Died **Florence, (Italy), 14 October 1831**

Jean-Louis Pons was the world's most successful visual discoverer of comets. Born into a poor family, Pons did not leave his mark on the astronomical community until 1801, when he logged his first discovery of a comet on 11 July. Pons's discovery (c/1801 N1), which he shared with **Charles Messier**, proved to be Messier's last. During his lifetime, Pons discovered or codiscovered a total of 37 comets. Of these, 26 are credited to his name.

In 1789, Pons gained a post as concierge at the Observatory of Marseilles and received instruction on the telescope from the astronomers. He was a fast learner and soon was allowed to observe with all the instruments. His favorite telescope was one with a 3° field of view. (This suggests a magnification around 15×.) Pons was known to possess an extraordinary ability to remember the star fields he had observed and thus to recognize changes within them.

In 1813, Pons was promoted to assistant astronomer and in 1818, assistant director of the Marseilles Observatory. In that year, he received the first of three Lalande Prizes for his discovery of three comets. **Joseph de Lalande**, director of the Paris Observatory, established the Lalande Prize in 1802, awarded each year for the outstanding achievement in astronomy. Pons's receipt of three Lalande Prizes may itself be unequaled.

On 26 November 1818, Pons discovered a comet that was later shown by German mathematician and astronomer **Johann Encke** to follow an elliptical orbit. Moreover, Encke demonstrated that Pons's comet (now designated 2P/1818 W1) was identical to that observed in 1786 by **Pierre Méchain** (2P/1786 B1) and in 1795 by **Caroline Herschel** (2P/1795 V1). The comet's orbital period is a scant 3.3 years, and Encke correctly predicted its return in 1822. For this reason, the comet is known today as 2P/Encke, although Encke himself always referred to it as Pons's comet. On account of gases that are vented from its rotating nucleus, the comet's orbital period decreases by about 2.5 hours per revolution. With its short period and one of the smallest perihelion distances (0.3 AU), comet 2P/Encke has perhaps evolved more rapidly than other periodic comets. It is associated with the annual Taurid meteor shower.

In 1819, Pons was appointed director of the observatory at the Royal Park La Marlia, near Lucca, Italy. He was called to that post by the widow of the former King Louis of Etruria, Duchess Maria Luisa of Bourbon, on the advice of Baron **János von Zach**, also of the Marseilles Observatory. In 1821, Pons received a second Lalande Prize, this time shared with Joseph Nicholas Nicollet, for discovering additional comets from his new observatory. After the Duchess died in 1824, Pons was invited to become director of the Florence Observatory by the Grand Duke of Tuscany, Leopold II. There, he found a total of seven more comets, and was awarded his third Lalande Prize in 1827, shared with **Jean Gambart**. Pons also received a Silver Medal from the Royal Astronomical Society for his discovery of two comets in 1822, at the same time that Encke was awarded the society's Gold Medal.

After 1827, Pons's eyesight began to fail, and he was forced to stop observing in 1831. Although he had no formal training in astronomy, Pons was a remarkable observer and shared the astronomical stage with many well-known scientists. Although possessing enormous patience and perseverance, Pons did not record the positions of his comets with much precision, making it more difficult for others to confirm his discoveries. While some comet discoveries are still made by visual means, most new comets are found today using photographic and electronic (charge–coupled device) imaging techniques. He is commemorated with a crater on the Moon's surface.

Robert D. McGown

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Pope Sylvester II

➔ **D'Aurillac, Gerbert**

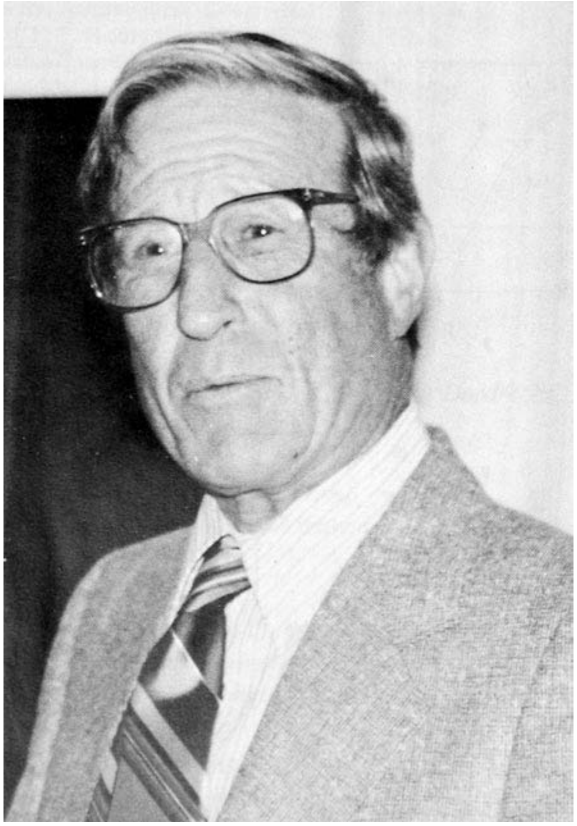
Popper, Daniel Magnes

Born **Oakland, California, USA, 11 August 1913**
Died **Los Angeles, California, USA, 9 September 1999**

Daniel Popper excelled in determining the properties of stars in binary systems. Much of modern stellar astrophysics is built on the foundation of stellar luminosities, radii and spectral types as a function of mass as determined by Popper.

The Popper family of Oakland, California, had already produced several community leaders by the time Daniel Popper received his AB and Ph.D. degrees at the University of California at Berkeley in 1934 and 1938, respectively. During this period, Popper's first published article, with **Lawrence Aller** and Alfred Mikesell, was on the spectrum of Nova Herculis 1934. His dissertation under **Arthur Wyse** was on the spectrophotometry of Nova Lacertae 1936. In this study, Popper correctly identified the greatly broadened lines of hydrogen and other common elements. In a third early paper on exploding stars, this time on supernova 1937C, Popper correctly differentiated the greatly broadened spectral lines in that object from those observed in Nova Herculis and Nova Lacertae, a difference that was not understood for an additional 40 years.

Although he began his career by working on exploding stars (novae and supernovae), Popper soon moved onto **Henry Norris Russell**'s "Royal Road to the Stars" – the study of eclipsing binary stars – and this is what turned out to be his life's work. Popper's early career featured short assignments at a number of locations beginning with a Martin Kellogg Fellowship at Eastman Kodak,



in Rochester, New York. There, he met his future wife, Catherine Salo; they were married in 1940 and had one son. On the recommendation of Lick Observatory director **William Wright**, Popper landed a job as resident astronomer at the newly dedicated McDonald Observatory in West Texas in 1939, remaining there for 3 years. After a year at Yerkes Observatory (1942–1943) Popper returned to Berkeley to join the war effort at the Radiation Laboratory, returning to Yerkes/University of Chicago as an instructor and then assistant professor at the end of World War II.

Popper was hired by the University of California at Los Angeles [UCLA], when that institution formed a new astronomy department in 1947, and remained there for the rest of his career. As a guest investigator at the Mount Wilson and Palomar observatories, one of his first results was the direct measurement of the gravitational redshift of a white dwarf, 40 Eridani B; his results agreed with the prediction of the general theory of relativity within the uncertainties inherent in the theory and the measurements.

Early in Popper's career, there was no real understanding of what today is thought of as stellar evolution. That understanding was gained in the 1940s, 1950s, and 1960s beginning with **Hans Bethe**'s idea that stars are powered by nuclear fusion reactions in their cores. Popper devoted his career to providing very accurate masses, radii, and luminosities of many pairs of stars (eclipsing binaries). Such systems are critical to understanding stellar evolution because both stars have the same age; determination of their properties provides perhaps the most critical tests of the theory of stellar evolution.

When Popper began his work, he soon came to realize that many of the previous spectroscopic workers had not recognized important subtleties inherent in the interpretation and measurement of eclipsing binary spectrograms and in the analysis of their light curves. He came to mistrust the accuracy of most of the earlier work – with good reason. Popper conveyed his misgivings forcefully to the astronomical community in a series of 18 articles entitled "Rediscussion of Eclipsing Binaries." In his published work, he established the guiding principles and detailed procedures needed to achieve accurate results. Following Popper's lead, this field of study advanced to routinely produce accuracies of better than 1% in both masses and radii.

One of Popper's few extended stays away from UCLA came in 1964 when, on a National Science Foundation Senior Research Fellowship, he worked on the inauguration of the stellar intensity interferometer program in Narrabri, New South Wales, Australia. While there, Popper helped the program focus on establishing accurate stellar temperature scales.

Popper was honored as the 1984 Karl Schwarzchild Lecturer of the Astronomische Gesellschaft.

Claud H. Lacy

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Poretsky, Platon Sergeevich

Born **Elizavetgrad (Kirovograd, Russia), 15 October 1846**
Died **Zhoved, (Chernigov Guberniya), Russia, 22 August 1907**

Platon Poretsky was a Russian mathematician and astronomer who developed a strong interest in mathematical logic. Poretsky, son of an army doctor, graduated from the department of physics and mathematics at Kharkov University. In 1870, he was awarded a fellowship by the department of astronomy and worked as an astronomer at the Kharkov Observatory. In 1876, Poretsky moved to Kazan University, where he was appointed its chief astronomical observer. There, he conducted meridian observations of stars in a zone assigned to the Kazan Observatory and published two volumes on the results.

In 1886, Poretsky defended a master's thesis that addressed the nature of errors associated with the observatory's meridian circle. Its theoretical part dealt with reducing the number of equations and unknowns in systems of cyclical equations relating to practical astronomy. But by a decision of the Department of Physics and Mathematics, Poretsky was awarded a doctorate in astronomy instead, based on the extraordinary quality of his work. He then became a *Privatdozent* (lecturer) in spherical trigonometry at Kazan University. Poretsky was also appointed secretary and treasurer of the physical–mathematical section of the Kazan Society of Natural Scientists (1882–1888) and supervised the publication of its *Proceedings*.

In succeeding years, Poretsky developed a deep interest in the emerging discipline of mathematical logic and became the first Russian scientist to lecture on the subject in 1888. His publications on mathematical logic (from 1884 until his death) were extensive and focused on the elaboration of Boolean algebras, on the study of the logics of classes and propositions, and the application of logical methods to the theory of probability. His influence on the development of mathematical logic was substantial, as is evidenced, for example, in the works of Archie Blake and Louis Couturat. Poretsky's poor health, however, forced him to take early retirement in 1889.

Poretsky's mathematical papers are preserved in the Kazan University Archives.

Yuri V. Balashov

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Porter, John Guy

Born **Battersea, (London), England, 5 November 1900**
Died **Hailsham, (East Sussex), England, 13 September 1981**

John Porter was a sophisticated astronomical computer as well as a dedicated astronomical educator. While a schoolteacher of mathematics and chemistry, he devoted himself as an amateur astronomer to computational astronomy, becoming the director of the British Astronomical Association [BAA] Computing Section in 1937. Porter became an expert on the computation of the orbits of meteors. By the end of World War II, Porter had refined his skills in this area so extensively that he was awarded a Ph.D. for his research on the orbits of meteors and comets. After the war, Porter and **John Prentice** were invited to join (Sir) **Alfred Lovell** at Jodrell Bank Observatory where they assisted in the analysis of radar observations of meteor streams. They showed from velocity profiles that meteors were members of the Solar System and not interstellar particles. Porter's book, *Comets and Meteor Streams*, spelled out these techniques for general use.

By 1949, Porter's reputation in computation was well established. He joined the staff of Her Majesty's Nautical Almanac Office at Herstmonceux, where he was responsible for computing the *Nautical Almanac and Astronomical Ephemeris*. Porter continued to lead the BAA Computing Section from this new venue, though many of his efforts on behalf of the *BAA Handbook* and other projects were by then nearly anonymous.

As a member of the International Astronomical Union, Porter served as president of Subcommission 20A on Orbits of Comets, and as chairman of the Working Group on Orbits and Ephemerides of Comets from 1955 to 1964. After a series of short-term appointments at Yale University in New Haven, Connecticut, USA, and then at the Jet Propulsion Laboratory in Pasadena, California, USA, Porter and his wife retired to Hailsham in about 1962. After his retirement, Porter published a comprehensive catalog of the most reliable orbits of 583 periodic comets observed between 240 BCE and 1965.

Quite apart from the successful career outlined earlier, Porter had a second equally successful career as a popularizer of astronomy. His first radio broadcast, delivered in 1946 on the discovery of Neptune, led to a series of popular weekly broadcasts that extended 15 years. Porter also developed a short series of television programs on astronomy for children, but he preferred the relative anonymity conferred by radio.

Porter was the recipient of the Walter Goodacre Medal and Gift of the BAA in 1965 and of the Jackson Gwilt Medal and Gift of the Royal Astronomical Society in 1968.

Thomas R. Williams

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Porter, Russell Williams

Born **Springfield, Vermont, USA, 13 December 1871**
Died **Pasadena, California, USA, 22 February 1949**

Arctic explorer, artist, and telescope maker Russell Porter was the cofounder of the amateur telescope making movement in the United States and architectural draftsman of the 200-in. Hale Telescope at Palomar Mountain.

Porter studied civil engineering at the University of Vermont and architecture at the Massachusetts Institute of Technology [MIT] but abandoned his coursework to pursue arctic exploration under the influence of admiral **Robert Peary**. Porter served as surveyor, astronomer, and artist on the ill-fated Fiala–Ziegler Expedition that failed to reach the North Pole (1903–1905). He also surveyed and mapped Mount McKinley in Alaska, but did not reach its summit.

Following these adventures, Porter temporarily settled at Port Clyde, Maine, where he married Alice Belle (1907); the couple had two children. There, he constructed his first telescopes and observatories, employing new optical and mechanical designs for instruments having fixed eyepieces. During World War I, he performed optical work at the United States National Bureau of Standards and was an instructor in design at MIT.

Porter published a quartet of drawings (1916) in *Popular Astronomy* that he labeled "Moonscapes." These depicted what an observer would see, if transported to the lunar surface in the vicinity of the crater Gassendi. Porter noted that "having himself spent many years above the Arctic Circle," he "was struck by a strange likeness of the moon's general aspect to our own polar regions." In turn, he completed "A New Projection of the Moon," depicting its appearance as if each point were simultaneously experiencing sunrise – a clever aid to helping the novice observer.

In 1919, Porter returned to his birthplace as an optical associate at the Jones and Lamson Machine Company. The following year, he founded the Amateur Telescope Makers of Springfield, whose clubhouse (Stellafane) on nearby Breezy Hill became the focus of the group's astronomical activities. The "Springfield" mounting was another of that group's innovations. A 1921 article written by Porter, "The Poor Man's Telescope," caught the attention of *Scientific American* assistant editor **Albert Ingalls**. A three-part series of articles, prepared and illustrated by Porter, launched the amateur telescope making movement, whose early phase culminated in publication of the three-volume classic, *Amateur Telescope Making, Book One, Two, and Three*.

In 1928, Porter was hired by **George Hale** to assist with the design of the 200-in. reflector on Palomar Mountain. Porter's earlier invention of the split-ring equatorial mounting was eventually incorporated into the Hale telescope (completed in 1948). Working only from blueprints, Porter produced the exquisite series of "cutaway drawings" of the giant reflector that revealed its intricate construction. He also designed the site-survey telescopes used in testing the Palomar seeing conditions, the new astrophysics laboratory at the California Institute of Technology, plus the mounting and dome for its Schmidt telescope. Additional freelance work included conceptual drawings of the Griffith Observatory, Los Angeles, and the star projector constructed by the Morrison Planetarium, San Francisco.

Porter was awarded honorary doctorates by two Vermont institutions: Norwich University (1946) and Middlebury College (1949). A crater on the Moon has been named for him.

Jordan D. Marché, II

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Posidonius

Born **Apameia, (Syria), 135 BCE**
Died **Rhodes, (Greece), 51 BCE**

Posidonius is responsible for an early measurement of the circumference of the Earth.

Posidonius was from a Greek family though he was born in Syria. He was raised in the Greek tradition and completed his education in Athens under the great Stoic philosopher Panaetius of Rhodes. His name is sometimes listed as Posidonius of Apameia, while at other times it is listed as Posidonius of Rhodes. The former obviously refers to the place of his birth, while the latter refers to the place where he ultimately taught.

Presumably, the influence of Panaetius is what brought Posidonius to Rhodes. Sometime after 100 BCE he is known to have become the head of the Stoic school at Rhodes, where he taught both **Cicero** and Pompey (the Great). In 86 BCE, Posidonius was sent as an envoy to Rome, where he met Gaius Marius, the Roman politician and general. It is also probable that it was around this time that he first met Pompey, who later visited him in Rhodes and became his pupil for a time. It is a remarkable testament to his abilities that we know as much about him as we do, as only fragments of his own writings have survived.

Posidonius is chiefly remembered for providing a value for the circumference of the Earth. There were, in fact, four attempts to measure the circumference of the Earth between the time of **Aristotle** and that of **Ptolemy**. Posidonius estimated that the distance from Rhodes to Alexandria was 5,000 stadia. (According to some estimates, a stade is roughly 185 m, though the one used by Posidonius may have been shorter.) He then observed that if the star Canopus was exactly on the horizon at Rhodes, then it was 1/4 of a sign (1/4 of 30°) about the horizon at Alexandria. This meant that the circumference of the Earth had to be 240,000 stadia, the accuracy of which depends on the value of the unknown stade. His result, whether based on observation or, more likely serving as an illustration, was likely a bit too large and not as accurate as that of **Eratosthenes**, but Posidonius's methods were a precursor to understanding the concept of latitude. It is interesting to note that later scholars indicate that Posidonius actually used different values both for the distance from Rhodes to Alexandria and for the height at which the star Canopus rose above the horizon. Both numbers as given earlier are actually incorrect for that approximate date. (Obviously, the distance never changes, but precession has changed Canopus's position from Posidonius's time.) Posidonius also made an estimate of the size of the Sun, but for its calculation used a value for the size of the Earth different from the one he had himself computed, thereby revealing something of his own convictions about their accuracy.

Most of our knowledge about Posidonius's astronomy comes to us from **Cleomedes**. Posidonius also showed a great interest in the earth sciences, having developed theories of clouds, mist, wind, rain, lightning, earthquakes, frost, hail, and rainbows in a work on *Meteorology*.

Ian T. Durham

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Pouillet, Claude-Servais-Mathias-Marie-Roland

Born **Cusance, (Doubs), France, 16 February 1790**
Died **Paris, France, 13 June 1868**

Mathias Pouillet (the name by which he was known) provided the first precise measurements of solar radiation, which he performed with instruments of his own design. Pouillet was the second of ten children of Ignace Denis Pouillet, a papermaker, and of Marie Françoise Rolland. He is said to have attended the lycée of Besançon, before he went to the collège of Tonnerre (Yonne), where he spent 2 years as a teacher of mathematics and where he received his baccalauréatit in 1811. Pouillet then became a student at the École Normale Supérieure, Paris from 1811 to 1813, where he earned his *licence ès sciences*, and he stayed on there as a tutor until 1815, subsequently becoming a *maître de conférences* in physics in the same establishment until 1822. In the meantime, he had earned the *agrégation pour les sciences* (in 1819). From 1817 to 1826, Pouillet also acted as a deputy teacher for the astronomer **Jean–Baptiste Biot** at the Faculté des sciences of Paris. In 1820, Pouillet was appointed professor at the Collège Bourbon (now the Lycée Condorcet), a post he held until 1829, and from 1826 to 1838 also assistant professor at the Faculté des sciences of Paris. He married Henriette Pichon in 1827, and in the same year he was invited to become the tutor of several children of the future king of France, Louis-Philippe.

Pouillet held very important positions at the Conservatoire (then royal) des Arts et Métiers: He was professor and assistant director from 1829 to 1832 (and also teacher of physics at the École Polytechnique for a year in 1831) and administrator (which in fact meant director) from 1832 until 1849, when he was dismissed because of the events of 13 June: an attempted revolt organized by A. A. Ledru-Rollin on the premises of the Conservatoire that Pouillet had not been able to control. In 1838, after the death of the incumbent, P. -L. Dulong, Pouillet held the chair of physics at the Faculté des sciences. He was compulsorily retired in 1852 because he refused to swear an oath of allegiance to the imperial government that took power after the coup d' état of 2 December 1851. He had lost both his children a few years earlier. Deeply affected by these personal and professional tragedies, he devoted his last years to the Académie des sciences and to experimental research, which he mainly carried out in his cottage at Épinay-sur-Seine.

Throughout his scientific career, Pouillet was a much-appreciated teacher of physics, lucid in his theoretical lectures and adept in the art of demonstrating experiments at whatever level he was teaching. A number of his lecture texts were printed in 1828, and he published his famous book *Éléments de physique expérimentale et de météorologie* during the years 1827–1830. A popular version of it was first published in 1850. As a member of the Société d'Encouragement pour l'Industrie Nationale, Pouillet also took an important part in reports on industrial exhibitions and many civil engineering works.

Pouillet carried out researches in various fields that were published as about 40 memoirs from 1816 onward, especially in the *Comptes rendus* of the Académie des Sciences. These dealt with optics, electricity, magnetism, meteorology, photography, photometry, thermal phenomena, and even with studies on the laws of population. In optics he investigated diffraction phenomena. In electricity, he improved the measurement of weak currents by means of his tangent and sine galvanometers. This allowed him in 1837 to verify very accurately Ohm's laws, which had been originally expounded in 1827.

Pouillet's astronomical research was mainly concerned with the measurement of solar radiation and the determination of the atmospheric effects on the recorded values. In 1824, he submitted a letter on the subject to the Académie des sciences through Dulong, and the same year he read a paper before the academicians. In 1838, Pouillet presented a substantial memoir in which he described the pyrheliometers he had designed for the purpose and reported the results of his observations. The data he obtained led to the first successful determination of a "solar constant," which he defined as the flux of total solar radiation received by a surface perpendicular to the Sun rays, for a mean Sun–Earth distance, at the upper limit of the atmosphere. He obtained a value of 1.7633 cal min^{-1} cm^{-2} (*i. e.*, 1,228 W m^{-2}), which turns out to be only 10% lower than the modern value, and hence better than the much overestimated values later given by Jules Violle in 1875 (2.54) and by Alexei Hansky in 1897 (3.4). In 1856, Pouillet designed an instrument he called an *actinographe*, which allowed him to record on a strip of photographic paper the effect produced by the intensity of the image of the Sun as it moved along the strip during the day. J. Stefan successfully used these actinometric observations together with Violle's ones to derive a value for the surface temperature of the Sun.

Pouillet was made a *Chevalier* of the Légion d'honneur in 1828, and an *Officier* in 1845. Meanwhile he had been elected a member of the Académie des sciences in 1837. He served several terms as a deputy for the French department of Jura and sat in the National Assembly from 1837 to 1848 on the government side.

Françoise Launay

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Pound, James

Born **Bishop's Canning, Wiltshire, England, 1669**
Died **Wanstead, (London), England, 16 November 1724**

James Pound made useful observations of Jupiter, Saturn, and the solar parallax, though he is remembered chiefly for the effects of the encouragement and astronomical training he provided to his nephew, **James Bradley**. Pound was educated at Oxford University from 1687 to 1694, when he received both his BA and his MA. By 1697, he had also obtained a medical degree and took orders in the Anglican Church. From 1699, he served as a chaplain in India, where he survived a massacre in 1705. In 1706, Pound returned to England, and was appointed as rector of Wansted in Essex the following year. He was elected to the Royal Society on 30 November 1699. On 14 February 1710, he married Sarah Farmer, a widow; they had a daughter, also named Sarah, born in 1713. After Pound's wife passed away in 1715, Pound was married in October 1722 to Elizabeth Wymondesold, who had a considerable fortune.

Pound made several astronomical observations in 1715, reporting his findings in *Philosophical Transactions*. In 1717, he mounted a 123-ft. focal length objective made by **Christiaan Huygens**; he used this "aerial" telescope to observe Saturn, its moons and rings, and also Jupiter with its satellites. Pound was one of the few observers who made significant contributions using this difficult form of telescope. **Isaac Newton** incorporated Pound's observations into the third edition of his *Principia*; **Pierre de Laplace** used his data to calculate Jupiter's mass.

Pound's financial circumstances enabled him to fund Bradley's education and astronomical interests. He made many observations with Bradley, and furthered his career by introducing him to **Edmond Halley** and **Samuel Molyneux**. Pound visited the latter regularly at his observatory in Kew. In 1717, Pound and Bradley attempted to measure the solar parallax, concluding that the Sun's distance lies between 93 and 125 million miles. The following year, Pound observed the components of the double star γ Virginis in order to determine a stellar parallax, a task Bradley continued in his observations of γ Draconis, which led to Bradley's discovery instead of the aberration of starlight in 1729. Together, Pound and Bradley also observed the opposition of Mars (1719) and the transit of Mercury on 29 October 1723.

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Poynting, John Henry

Born **Monton, (Greater Manchester), England, 9 September 1852**
Died **Birmingham, England, 30 March 1914**

John Poynting was a physicist, mathematician, and inventor. He was the youngest son of Reverend T. Elford Poynting and Elizabeth Long. He attended Owens College, Manchester, and Trinity College, Cambridge (1872–1876), and was elected fellow of Trinity College in 1878. He was appointed professor of physics at the Mason College Birmingham (later University of Birmingham) in 1880 and remained there until his death. He married Maria Adney in 1880 and had a son and two daughters.

Poynting is well known for the Poynting vector, which describes the rate at which energy is carried by electromagnetic radiation. It was first introduced in his paper "On the Transfer of Energy in the Electromagnetic Field" (1884). He was also known for his discovery that infrared radiation causes small particles that orbit the Sun to spiral toward and plunge into the Sun. This idea was later developed by the American physicist **Howard Robertson** and is known as the Poynting–Robertson effect. Poynting also invented a method for finding the absolute temperature of celestial objects. He calculated the mean density of the Earth and made a determination of the gravitational constant. The results were published in *The Mean Density of The Earth* (1894) and in *The Earth: Its Shape, Size, Weight and Spin* (1913).

The Cambridge University Press published Poynting's *Collected Scientific Papers* in 1920. His other works include *The Earth* (1913) and *The Pressure of Light* (1910). Poynting was awarded the Adams Prize of Cambridge for his essay on *The Mean Density of The Earth* in 1894. He received the Hopkins Prize of the Cambridge Philosophical Society (1903) and the Royal Medal from the Royal Society (1905).

Suhasini Kumar

Selected Reference

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Prager, Richard

Born **Hanover, Germany, 30 November 1883**
Died **Boston, Massachusetts, USA, 20 July 1945**

German variable-star astronomer Richard Prager compiled a three-volume catalog of variable stars and their literature, which was the primary source of information on these between 1925 and 1949. He was educated at Hamburg (1901) and Göttingen (1903) universities, receiving a Ph.D. from Berlin in 1908 and holding a position as an assistant at the Berlin Academy of Sciences for the next year. In 1909, Prager accepted a position as a section chief at the Observatorio Astronomico Nacional in Santiago de Chile, where he worked with **Friedrich Ristenpart** during the latter's abortive attempt to rejuvenate the facility. There Prager made a number of measurements of positions of Solar System objects including 139 of comet 1P/Halley during its 1910 appearance.

Returning to Germany in 1913, Prager was first assistant and then observer at the Berlin–Babelsbürg Observatory, being appointed professor in 1916. Together with **Paul Guthnick**, he exploited the then revolutionary potassium iodide cell to perform precision photoelectric photometry of variable stars. Of Jewish ancestry, Prager was imprisoned by the Nazis at Potsdam in 1938, but released to immigrate to London when the British Home Office accepted his application for asylum at the urging of the British astronomical community. He lectured to the Royal Astronomical Society in January 1939 before going on to Harvard College Observatory under a program for displaced scholars (in which **Harlow Shapley** played a significant part). Prager carried out some mathematical work for the navy during World War II, but he never entirely recovered from the physical hardships of imprisonment and separation from his family, and died after a succession of illnesses.

Prager's three volumes of *Geschichte und Literature des Lichtwechsels der Weranderlichen Sterne*, the last published in English from Harvard in 1941 as *History and Bibliography of the Light Variations of Variable Stars*, were superceded only after 1949, when, at the request of the Commission on Variable Stars of the International Astronomical Union, Boris V. Kukarkin and **Pavel Parenago** took up the task of compiling and evaluating the literature on this important astronomical subject. Prager served as secretary of the Astronomische Gesellschaft (the German astronomical society) from 1930 to 1936, but was debarred from membership in the International Astronomical Union because Germany was not permitted to join until after World War II.

Leif J. Robinson

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Prentice, John Philip Manning

Born **Stowmarket, Suffolk, England, 14 March 1903**
Died **Stowmarket, Suffolk, England, 6 October 1981**

John Prentice discovered the Giacobinid (Draconid) meteor shower and Nova DQ Herculis 1934, but his main contributions to astronomy came through his careful supervision of the British Astronomical Association [BAA] Meteor Section for over 30 years. Prentice played an important role in establishing radar observation as a primary technique for studying meteors.

A lawyer by profession, Manning Prentice (as he was known to his friends) acquired an interest in astronomy as a schoolboy. He first began observing the Moon and planets with a small refractor, and later meteors with his naked eye. After joining the BAA in 1919, Prentice continued his meteor observations and was appointed leader of the BAA Meteor Section in 1923, holding that position until 1954.

In 1915, Reverend Martin Davidson (1880–1968) pointed out that the orbit of the short-period comet 21P/Giacobini – Zinner passed close enough to that of the Earth that it might result in a meteor shower on about 10 October each year. No such activity was seen until **Andrew Crommelin** calculated that on 10 October 1926 the orbits of the comet and the Earth would intersect. Acting on Crommelin's prediction, Prentice took up a routine watch the previous evening and was rewarded with the observation of a strong meteor shower – Prentice estimated meteors appeared at a rate of 17 per hour for one observer – with a radiant very near that projected by Davidson. **William Denning** published a similar conclusion about this shower at an earlier date than Prentice, but priority for the discovery clearly belongs to Prentice as the earliest observer. A spectacular return of the Giacobinid meteor shower in 1933, when the Earth crossed the comet's orbit 80 days after the passage of the comet (as opposed to 19 days before the comet's passage in 1926), confirmed not only the relationship of the shower with the comet but also revealed that the duration of the shower was sharply limited to only 4½ hours. The zenith hourly rate for the

1933 Giacobinid shower was estimated at between 4,000 and 6,000 meteors per hour. Unfortunately, the skies were cloudy in England, and the information on this shower was provided by Reverend William Frederick Archdall Ellison (1834–1936) at the Armagh Observatory and by observers on the European Continent.

Prentice's familiarity with the night sky was an important prerequisite for his program of meteor observation and also contributed to his discovery, early on the morning of 13 December 1934, of a nova in the constellation of Hercules. While taking a break from his tiring routine of meteor counting, Prentice noticed something wrong in the appearance of the head of Draco. The problem was quickly traced to an interloping star that was promptly reported to the Royal Greenwich Observatory. Prentice's expeditious reporting facilitated valuable premaximum spectroscopic observation of Nova DQ Herculis. An independent discovery of this nova was made within hours at Delphos, Ohio, by another amateur astronomer, **Leslie Peltier**.

In June 1937, Prentice married Elizabeth Mason Harwood; their union resulted in the birth of four children. The resulting obligations, as well as those associated with his leadership in the congregation of the Stowmarket Congregational Church, must have increased the burden of his avocational interests, but Prentice's zeal for observation remained comparatively undiminished. A further complication arose as a result of the bombing of the church in 1941. For 14 years thereafter, Prentice shouldered a heavy burden as he led the membership's effort to rebuild the structure and preserve the integrity of the congregation. Prentice was active as a leader of youth activities in the church and served as a lay minister and church secretary as well.

After World War II, (Sir) **Bernard Lovell** contacted Prentice and his BAA meteor section for assistance in tracing the relationship between meteor activity and apparently spurious radar signals, interference that could not be traced to cosmic-ray activity. During the Perseid shower in August 1946, Prentice traveled to Jodrell Bank to assist with the correlation of radar signal reception with the appearance of specific meteors; the correlation was immediately evident. Prentice and **John Porter** worked with Lovell and others at Jodrell Bank to apply this technique to good advantage in investigations of meteor streams during daylight hours, and streams of meteors too faint to be seen with the naked eye at night.

In 1935, the BAA and American Association of Variable Star Observers honored Prentice for his discovery of Nova DQ Herculis by awarding him their Walter Goodacre Medal and D. B. Pickering Medal, respectively. In 1953, the Royal Astronomical Society honored his work on meteors with the award of its Jackson-Gwilt Gift and Medal while the University of Manchester conferred an honorary master of arts degree on Prentice in that same year.

Thomas R. Williams

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Preussen, Pilgrim Zeleschicz von

➜ **Pèlerin de Prusse**

Pritchard, Charles

Born **Alberbury, Shropshire, England, 29 February 1808**
Died **Oxford, England, 28 May 1893**

Reverend Charles Pritchard pursuaded astronomers to take accurate positional measurements from photographic plates. Pritchard was the fourth son of William Pritchard. He married Emily Newton in 1834 and Rosalind Campbell in 1858.

Pritchard was educated at Merchant Taylors' and Christ's Hospital schools, then Saint John's College, Cambridge. He graduated first in 1830 and then received an MA from the same institution in 1833. Pritchard became a fellow of Saint John's College in 1832 and an honorary fellow in 1886. He earned another MA from Oxford in 1870 and a DD in 1880. Pritchard was named a fellow of New College in 1883.

Pritchard had a successful career as headmaster of Clapham Grammar School, London (1834–1862). He was particularly noted for his teaching of mathematics and sciences. Pritchard also equipped the school with a small observatory. Upon his retirement to the Isle of Wight he became involved in the current controversies between science and religion. Pritchard was opposed to Darwinism and used his scientific accomplishments in defense of the Christian religion. He was subsequently appointed as Hulsean Lecturer (Cambridge) in 1867 and then as Savilian Professor (Oxford; at age 62) from 1870 to 1893.

At Oxford, Pritchard oversaw a complete renovation of the observatory, obtaining new instruments and appointing competent assistants. He engaged the observatory in a number of research projects of specific duration. Pritchard started work on a study of lunar libration using photography; however, this work was not successful and was never published. He compiled a catalog of star magnitudes using a wedge photometer; this was published as the *Uranometria nova Oxoniensis* (1885). Pritchard embarked on a program to measure stellar parallax using photography. He also committed the Oxford Observatory to the *Carte du Ciel* project, obtaining a suitable telescope and initiating the survey.

Pritchard was awarded the Gold Medal of the Royal Astronomical Society in 1886 and a medal of the Royal Society in 1892. He was a fellow of the Royal Astronomical Society from 1849 (its president from 1866 to 1868), fellow of the Royal Society from 1840, and also a fellow of the Geological Society and Cambridge Philosophical Society.

Letters and some other papers by Pritchard are kept in the Library of the Royal Astronomical Society.

Mark Hurn

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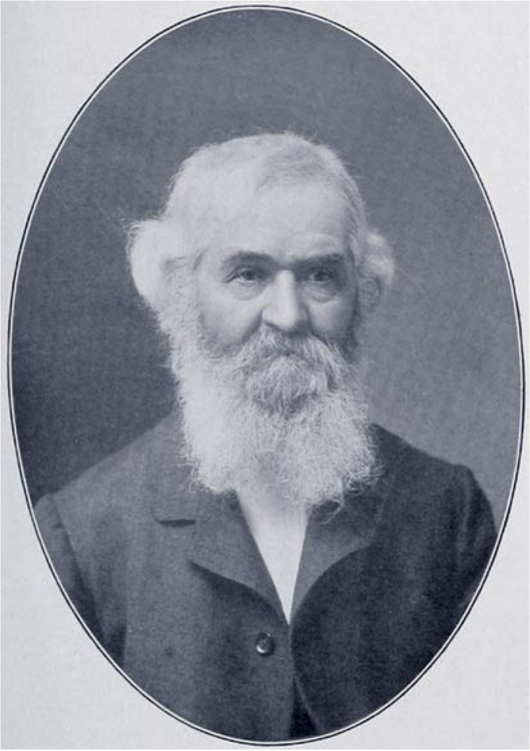
Pritchett, Carr Waller

Born **Henry County, Virginia, USA, 4 September 1823**
Died **Independence, Missouri, USA, 19 March 1910**



Starting in 1878, and in every apparition since, Jupiter's Great Red Spot has been continuously visible. In that year, it was first spotted by Reverend Carr Pritchett of Glascow, Missouri, USA. (Sporadic sightings of the Great Red Spot appear to go back to the time of **Giovanni Cassini**.)

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See, T. J. J. (1910). "Pritchertt, Carr Waller." *Popular Astronomy*. 18: 348.

Proclus

Born **Byzantium (Istanbul, Turkey), *circa* 411**
Died **Athens, (Greece), 17 April 485**

Head of the Athens Academy in the 5th century, Proclus promoted astronomy in mathematics, cosmology, physics; in empirical observation and instrumentation; and in higher education, proposing that celestial objects have their own self-movement in free space, that our system can be heliocentric, and that cosmic space consists of pure light. He was the last major thinker of Antiquity, and also the one who systematized Greek knowledge in the form it was transmitted to Islam and western Europe.

Proclus' Greek–speaking parents, Patricius and Marcella, moved from Byzantium to Xanthus, a district of Lycia in Asia Minor, probably by 415. Proclus studied rhetoric, Roman law, and Latin at Alexandria. He visited Byzantium at the time of the revival of advanced schools inspired by the Athenian-born Empress Eudocia (425). There he experienced a momentous conversion to Athenian philosophy. On his return to Alexandria, Proclus studied **Aristotle** and mathematics, which included astronomy. He then traveled to Athens (430), where he was quickly embraced by the leaders of the Neoplatonic "academy," and studied the philosophy of Aristotle, **Plato**, and other Greek thinkers. Proclus rose to become head of the premier center of higher learning of the Roman Empire at the age of 25. Around 450, he traveled for a year's sabbatical to the region of Lydia in Asia Minor, to avoid persecution by the Christian authorities. His chief surviving book on astronomy was written just after this trip. In Athens, Proclus pursued a career as a teacher, author, administrator, and influential figure within the empire, which left his followers in awe, as recorded by his biographer, Marinus. The biography concludes with a valuable reference to two solar eclipses at Athens, one precisely observed (14 January 484) and one predicted (19 May 486).

Proclus' integration of astronomy and physics with his metaphysics freed scientific thinking from constraints owed to Aristotle and **Ptolemy**. But he was not just a theoretician. He promoted practical and empirical knowledge, for they combine critical reasoning with direct perception of the appearances of reality. Proclus' chief astronomical treatise, the outline *(Hypotyposis) of the Astronomical Hypotheses*, contains a detailed description of how to construct and calibrate the spherical armillary astrolabe, and how to make observational measurements of the Moon and the stars; he noted the existence of optical binary stars. He also refers to the use of Heron's water clock to measure the Sun's diameter, to the meteoroscope instrument, and to the actual construction of ephemerides tables. He made some of the last reliable astronomical observations of Antiquity (475).

Proclus' views on astronomy are part of his responses to the core questions: How much can the appearances of things tell us about their deep nature? What is the nature of reality? For Proclus the celestial objects are "self-substantiated" agents with the power to move freely of their own accord. They orbit according to their own natural, unimpeded motion, and move in the three dimensions of free space without the need of celestial spheres. Proclus further proposed that every fixed star and planet must have its own spin around its axis. He went so far as to suggest that the Earth itself is like a star, and if it were not for the inertness characteristic of its predominant physical property, it should move circularly.

Proclus advanced the heliocentric view. He accepted that the celestial bodies revolve around the Earth as center but only in their capacity as earth-like bodies. Since it is their self-power that really matters, they should be arranged around the center of most power: the Sun. The Sun is also in the middle of a system consisting of the five observed planets, the Moon, and the Earth's four elements. Further, Proclus speculated that every planet has its own group of attendant "satellites."

Proclus poured scorn on astronomers such as Ptolemy, who believed that inventing epicyclic and eccentric spheres could explain away the apparent irregular movement of the planets and the Sun and the Moon. Proclus took these irregularities seriously, as problems challenging us to reconcile our current level of understanding with that proper to deeper reality. He also rejected **Hipparchus**' discovery of the "precession," as described by Ptolemy, and Ptolemy's interpretation that the precession involves a backward movement of all the stars. For Proclus the stars are fixed in their constellations and do not precess. Proclus' *Outline of the Astronomical Hypotheses* contained the only critical evaluation of Ptolemy in antiquity, and rejected his speculations on many counts.

Proclus also rejected Aristotle's fifth element for the heavens. For Proclus the heavens have the same four constituents (fire, air, water, and earth) as the Earth, but in a different state of matter. This contains the "summits" of all the elements, where the properties of fire prevail. He concluded that the celestial bodies must have some Earth properties also, to be opaque (as in eclipses) and have gravity. Above all, he asserted that there is one science for both the heavens and Earth, not separate ones.

In cosmology, Proclus was the first to propose that space must be a three-dimensional body of a special kind that allows normal bodies to coexist with it. He speculated that there is a cosmic space, a body of pure, invisible light, in which the entire Universe is immersed.

Proclus instilled astronomical interest in his students, including Marinus, his successor at the Athenian School; **Ammonius**; and Ammonius' brother **Heliodorus**. The latter records Proclus' observation of an occultation of Venus by the Moon (475) from Athens. Ammonius' students **Simplicius** and the Christian **John Philoponus** wrote the major commentaries on Aristotle, but followed Proclus on the rejection of Aristotelian physics, and accepted most of his views on the celestial bodies and the elements.

Through the Byzantine emigrés Gemistos Plethon and John Bessarion, Proclus and Ptolemy spread to Renaissance Europe. By the 16th to 17th centuries Proclus' mathematical and astronomical achievements gained wide recognition. Proclus' *Commentary on Euclid* was highly regarded and discussed in **Galileo Galilei**'s circle. **Nicolaus Copernicus** cited it in the *Revolutions of the Heavenly Spheres*, and **Johannes Kepler** did likewise in the *Harmonices Mundi* (1619). Kepler quoted Proclus repeatedly and praised him as a true precursor of the heliocentric theory.

Proclus' name has been given to a lunar crater near the Sea of Tranquillity.

Lucas Siorvanes

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Proctor, Mary

Born **Dublin, Ireland, 1862**
Died **probably London, England, 1957**

Mary Proctor never became a professional astronomer, but was widely known for numerous articles and books on the subject.

Proctor was the daughter of **Richard Proctor** and his first wife, Mary (*née* Mills) Proctor. Mary's father was a well-known astronomer, lecturer, and writer, born in London and a graduate of Saint John's College, Cambridge. It was from him that Mary acquired her astronomical knowledge and her love for writing. From an early age, she took pride in the care of his library; as a young woman, she arranged his letters and corrected the galley proofs of his books. She graduated from the College of Preceptors at London in 1898.

Proctor's mother died in 1879. When her father remarried in 1881, the Proctor family immigrated to America and settled in Saint Joseph, Missouri. Proctor studied writing and assisted her father in the production of a new journal, *Knowledge*, which he founded and edited that same year. Among her earliest published writings was a series of articles on comparative mythology. She also began a secondary career as a lecturer on astronomy, following a very successful appearance at the World's Columbian Exposition at Chicago in 1893. Proctor's ambition to write a book was first realized with the 1898 publication of *Stories of Starland*, which was adopted by the New York City Board of Education. She attended classes at Columbia University and taught astronomy in private schools.

Many of Proctor's articles and books were aimed at younger audiences, and Proctor became known as the "children's astronomer." Her literary works included *Wonders of the Sky*, *Everyman's Astronomy*, *The Romance of Comets*, *Legends of the Stars*, and *Half-Hours with the Summer Stars*. Her books were easy to read, accurate, informative, and well illustrated. Proctor was widely respected by professional astronomers, and in 1898 was elected to membership in the American Association for the Advancement of Science. She was elected a fellow of the Royal Astronomical Society in 1916.

In *The Book of the Heavens*, published in 1924, Proctor wrote: "Some of my readers may become great astronomers; for that reason I have [included] … accounts of … some leading observatories of the world [so] that boys and girls may see astronomers of today at work." She never married. A 12-mile diameter lunar crater has been named for her.

Patrick Moore

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Proctor, Richard Anthony

Born **Chelsea, (London), England, 23 March 1837**
Died **New York, New York, USA, 12 September 1888**

Richard Proctor was principally an expositor of science, especially astronomy. He wrote prodigiously on the latter topic, and gained considerable fame through his articles and books. In 1854, Proctor worked as a clerk in the London Joint Stock Bank. A year later, he enrolled at King's College, London, where he studied theology and mathematics. Proctor graduated in 1860 from St. John's College, Cambridge, as 23rd Wrangler. That year he also married his first wife, Mary Mills.

"A few months after leaving Cambridge," Proctor tells us, "in my quiet home at Ayr, free of all anxieties about maintenance (for I had inherited ample means), I began in a very modest and quiet way the study of some astronomical matters, to which my attention had been attracted by two books picked up at a book stall in Glasgow." His first published article took him 6 weeks to prepare. "Often I would not complete more than four or five lines in a day with which I was satisfied, so that … my work went on very slowly indeed." The piece, entitled "Colours of Double Stars," appeared in *Cornhill Magazine* (1865).

As a form of therapy, following the death of his eldest son, Proctor undertook a "work which would occupy me," he wrote, "for at least a year." In due course, his first astronomical treatise, *Saturn and Its System*, was completed (1865). This contained the first popular account of **James Maxwell**'s theory of the discrete nature of the planet's ring system.

Although commercially unsuccessful at first, the book established Proctor's reputation among those best equipped to judge its merits, and in 1866 he was elected a fellow of the Royal Astronomical Society. That same year, however, Proctor suffered a serious financial crisis when the New Zealand bank, in which the bulk of his assets were invested, collapsed.

Out of necessity, Proctor taught mathematics at the Military School, Woolwich. But by the autumn of 1867, he had definitely settled on a literary career. Passing "through experiences enough to age a man ten years in as many weeks," Proctor eventually succeeded, and in 1872 became one of the secretaries of the Royal Astronomical Society, and editor of its journal, the *Monthly Notices*. From that time onward, his output was prodigious and diverse.

It was Proctor's intention to produce original works that formed a standard embodiment of the astronomical knowledge of the last quarter of the 19th century. His exhaustive account of the Venus transits of 1874 and 1882 was characterized by one biographer as "the best popular exposition of the nature and use of that phenomenon that has yet appeared." Proctor wrote, in all, around 57 books, his last being *Old and New Astronomy* (1892), a large treatise on which he reported, "I intend … putting into final form the results of my studies, now scattered through my essays, lectures and magazine articles." This was left unfinished at the time of Proctor's death, but enough materials had been assembled that his friend, **Arthur Ranyard**, could complete the task.

In 1867, Proctor prepared a map of Mars from the 1864–1865 drawings by Reverend **William Dawes**. Employing considerable cartographic skills, he applied names to supposed continents, seas, bays, and straits, thus showcasing current beliefs about physical conditions on the planet. A small forked bay-like marking, named after Dawes (now Sinus Meridiani), was adopted as the Martian prime meridian. Proctor also deduced an extremely accurate rotation period of Mars, from historic drawings of the red planet. In 1870, Proctor plotted the positions and proper motions of roughly 1,600 stars. As a result, he found that certain clusters shared a common direction of travel through space, a phenomenon he dubbed "star drift." Around 1873, Proctor conjectured that the craters of the Moon were impact features and not the result of volcanic eruptions. It would be decades before this idea gained wider acceptance.

Proctor's first wife, Mary, died in 1879. He then went on a 2-year lecture tour of the United States. In 1881, Proctor met and married the widow of Robert J. Crawley; the couple settled in Saint Joseph, Missouri (her hometown). That same year, he founded the popular science magazine *Knowledge*, and continued as its editor until his death from yellow fever. One year earlier, Proctor and his wife had moved to Orange Lake, Florida. His daughter, **Mary Proctor**, followed in her father's footsteps and published many popular books on astronomy. A crater on Mars has been named in Proctor's honor.

Richard Baum

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Profatius

➔ **Jacob ben Makhir ibn Tibbon**

Prosperin, Erik

Born **Närlinge, Upland, Sweden, 25 July 1739**
Died **Upsala (Uppasala), Sweden, 4 April 1803**

Uppsala University's Erik Prosperin calculated an orbit for the new, seventh planet spotted by **William Herschel**. Prosperin wanted to call the discovery Neptune; instead, this name eventually went to the *eighth* planet from the Sun.

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Alexander, A. F. O'D. (1965). *The Planet Uranus: A History of Observation, Theory and Discovery*. New York: American Elsevier.

Przybylski, Antoni

Born **Rogozno, Poland, 1913**
Died **Queanbeyan, New South Wales, Australia, 21 September 1984**

Polish–Australian astrophysicist Antoni Przybylski discovered (1960) one of the most unusual stellar spectra: Przybylski's Star (HD 101065) is the only astronomical object to exhibit the presence of holmium. Przybylski was a protégé of **Richard Van der Riet Woolley**.

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Ptolemy

Flourished **Alexandria, (Egypt), second century**

Hundreds of years of Greek geometrical astronomy were systematized, with rigorous demonstrations and proofs, by Claudius Ptolemaius. His intent was to do for applied mathematics what Euclid had done for pure mathematics (geometry). Ptolemy produced handbooks containing all that was known about astronomy, optics, geography, astrology, musical theory, geometrical constructions using spherical projection, the structure and size of the Universe, and mechanics. Although his primary goal was to summarize what was already known, Ptolemy also advanced astronomical knowledge so far as to earn for himself a reputation as the greatest astronomer of the ancient world. He showed how, based upon observation and empirical data, geometrical models could be constructed that simulated nature. His astronomical textbook surpassed all that had gone before and dominated future astronomy for well over a millennium. In replacing much of previous astronomy, however, Ptolemy helped cause the loss of a vast body of earlier data.

Of the man himself almost nothing is known. His recorded observations purportedly were made – some assert they were fabricated – between the 9th year of Hadrian's regime (125) and the 4th year of Antoninus Pius (141) "in the parallel of Alexandria." Most writers assume that Ptolemy worked in Alexandria, Egypt, but according to **Olympiodorus the Younger**, a philosopher teaching in Alexandria in the 6th century, Ptolemy worked for 40 years at Canopus, a town 15 miles to the east of Alexandria (and hence in the same parallel). One tradition even has it that Ptolemy in 147 erected in the temple of Seraphis at Canopus a pillar to commemorate

his discoveries. Wherever he actually resided, Ptolemy rightly is associated with Alexandria, whose library provided him with the observations of his predecessors, upon which he constructed his great synthesis.

Ptolemy's mathematical systematic treatise of astronomy, *The Mathematical Syntaxis*, soon attracted the appellation *megiste*, the Greek adjective for "greatest," which was transliterated into Arabic. With the addition of the definite article *al*, Ptolemy's complete exposition of mathematical astronomy became, upon passing from Arabic into Medieval Latin, the *Almagest*. Ptolemy's treatise was lost in the west soon after its completion, but was copied and studied in the Byzantine Empire. Manuscript versions in the original Greek and dating from the 9th century are extant, as are Arabic translations dating from the 11th century and later. So is a Latin translation from Arabic made in 1175. This was rendered, in 1515, into the first printed version of the *Almagest*.

The *Almagest* begins with a brief introduction to the nature of astronomy and a presentation of the necessary trigonometric theory and spherical astronomy. Then come theories of the Sun and the Moon, an account of eclipses, discussion of the fixed stars, and finally a discussion of the planets. The motivation underlying Ptolemy's study is found in an epigram:

> I know that I am mortal and the creature of a day; but when I search out the massed wheeling circles of the stars, my feet no longer touch the Earth, but, side by side with Zeus himself, I take my fill of ambrosia, the food of the gods.

Ptolemy proposed to begin with reliable observations and attach to this foundation a structure of ideas using geometrical proofs. Had he completely replaced the Greek deductive geometrical science he inherited with an inductive observational procedure, the result would have been a scientific revolution. However, determining the reliability of observations other than from their agreement with the very theory that were to be used to confirm proved a major problem for Ptolemy.

Ptolemy sought to explain the apparent irregularity of the Sun's motion as a combination of regular circular motions (defined as motions that cut off equal angles in equal times at the center of the circle). In the eccentric hypothesis, the circle carrying the Sun was not centered on the Earth, and thus regular motion as viewed from the center of the Sun's orbit appeared irregular when viewed from the Earth. In the epicycle hypothesis, a small circle (the epicycle) had its center fixed on a large circle (the deferent), and the combination of their regular motions was irregular. In the case of the Sun, either hypothesis could produce the observed motion. The hypotheses were interchangeable in a mathematical sense, though not in a physical sense.

Ptolemy next presented a table of the motions of the Moon and showed that the eccentric circle and the epicycle hypotheses could produce the same appearances. He reported lunar observations of greater accuracy than ever made before, using an astrolabe, which he described in detail.

To reproduce the more complex movements of the planets, Ptolemy found it necessary to employ both hypotheses simultaneously. Furthermore, difficulties in matching theory to observation eventually forced Ptolemy to violate his own definition of uniform circular motion. The violation would become one of the major causes of dissatisfaction with Ptolemy's system, leading to **Nicolaus Copernicus**' revision and revolution 14 centuries later.

In several instances in the *Almagest*, reported observations match corresponding theory more accurately than could be expected of random observations subject to probable errors, and Ptolemy is thus suspected of having fabricated the purported observations. There exists, however, a close agreement between Ptolemy's numerical parameters and modern observational values, so Ptolemy must have had a large, if unreported, body of real observations from which he derived his accurate parameters. Once a theory and its quantitative parameters were determined from a large body of real observations, Ptolemy next might have selected from among the observations a few in best quantitative agreement with the theory and then presented these examples to illustrate – not necessarily to determine, or to prove – the theory. Furthermore, Ptolemy was working within the tradition of Greek geometrical astronomy originally concerned almost totally with geometrical procedure and very little, if at all, with specific numerical results. The objective of the *Almagest* could have been didactic. Ptolemy may not have intended to deceive his readers, but he was less than candid concerning the manner in which he arrived at his results and was most remiss if his conduct is judged against the ethics of modern science.

Another question involving Ptolemy and his astronomy is whether the many circular motions compounded to determine the trajectory of a planet had a physical reality. Did Ptolemy envision actual physical structures in the heavens carrying around the planets? Or were his planetary theories merely means of calculating the apparent places of the planets without pretending to represent the true system of the world? His lunar theory predicted the Moon's positions in longitude and latitude accurately but greatly exaggerated the monthly variation in the Moon's distance from the Earth. Hence, the argument goes, Ptolemy could not have intended that the theory be interpreted realistically. In one of his other books, however, Ptolemy showed a concern with the physical world. In the *Planetary Hypotheses* he nested the mechanism of circles for each planet inside a spherical shell between adjoining planets. And a passage in the *Almagest* is susceptible to the interpretation that a construction in the heavens made not of wood, nor of metal, nor of other earthly material, but of some divine celestial material offering no obstruction to the passage of one part of the construction through another, controlled the motions of the planets.

After all is said – the charges of fraud leveled, the scientific shortcomings revealed, and the unanswerable questions exhausted – the historical influence and significance remain. Ptolemy's *Almagest* was the culmination of Greek astronomy, unrivaled in Antiquity, surpassing all that had gone before, and not itself surpassed for some 1400 years, until the time of Copernicus.

Norriss S. Hetherington

Alternate name

Claudius Ptolemaius

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Puiseux, Pierre-Henri

Born **Paris, France, 20 July 1855**
Died **Fontenay, Jura, France, 28 September 1928**

Pierre Puiseux produced a series of studies on the Moon, addressing its motion, its surface, and its internal structure. He was the son of Viktor Puiseux (1820–1883), an astronomer and mathematician as well as a member of the Academy of Sciences, and of Laure Louise Jeannet (died: 1858). In 1865, Puiseux began to attend the high school in Saint-Louis; in 1875, he became a university student at the École Normale Supérieure, where he received his Ph.D. in mathematical sciences in 1879. On 20 June 1883, he married Laurence Elisa Marie Béatrice Bouvet, with whom he had seven children. Puiseux was well-known as a mountain climber. He succeeded in several first ascents and contributed to the exploration of several mountains in France, Switzerland, Sweden, and Italy. He frequently published mountaineering articles in *Annuaire du Club alpin français* as well as in the journal *Montagne*.

Puiseux worked his way up the career ladder at the Observatory of Paris, starting as a student astronomer (1879) before taking the positions of assistant astronomer (1881), associate astronomer (1885), astronomer (1904), and, after his retirement in 1917, honorary astronomer. From 1880, he lectured at the Faculty of Science in Paris, since 1897 as a honorary professor. In 1904, Puiseux was appointed to a lectureship in celestial mechanics.

In his dissertation of 1879, Puiseux analyzed the secular acceleration of the Moon. As an astronomer at the observatory, he devoted his studies to the photography of celestial bodies, to the realization of an international celestial map, and to the analysis of the Moon's topography and libration. He was sent abroad for scientific missions several times, for example, to Fort-de-France (Martinique) in 1882 for the observation of the transit of Venus, and to Cistierna (Spain) in 1905 for the observation of a solar eclipse. In addition to his books on the internal structures of the Earth and the Moon, and his photographic atlas of the Moon, Puiseux wrote numerous treatises published in *Annales de l'Observatoire de Paris*, in *Comptes-rendus de l'Academie des sciences*, and in the *Bulletin de la Société Astronomique de France*.

From 1906 to 1917, Puiseux supervised the photographic mapping of the sky. In 1907 and 1910, he served as secretary at the congresses of the International Union for Solar Research, which took place in 1910 at Mount Wilson Observatory in California. In 1909, he participated as the secretary at an international conference for the edition of celestial maps.

Puiseux was awarded the Valz Prize of the Academy of Sciences in 1892, the Lalande Prize of the Astronomical Society of France in 1896, and the Janssen Prize of the Academy of Sciences in 1908. He became knight of the Legion of Honor in 1900, president of the Astronomical Society of France in 1911, member of the Astronomy Section of the Academy of Sciences in 1912, associate member of the Royal Astronomical Society in 1917, and honorary president of the French Alpine Club. In 1935, a crater on the Moon was named for Puiseux to credit his scientific achievements (latitude 27°.8 S, longitude 39°.0 W, diameter 24 km).

Thomas Klöti
Translated by: *Andreas Verdun*

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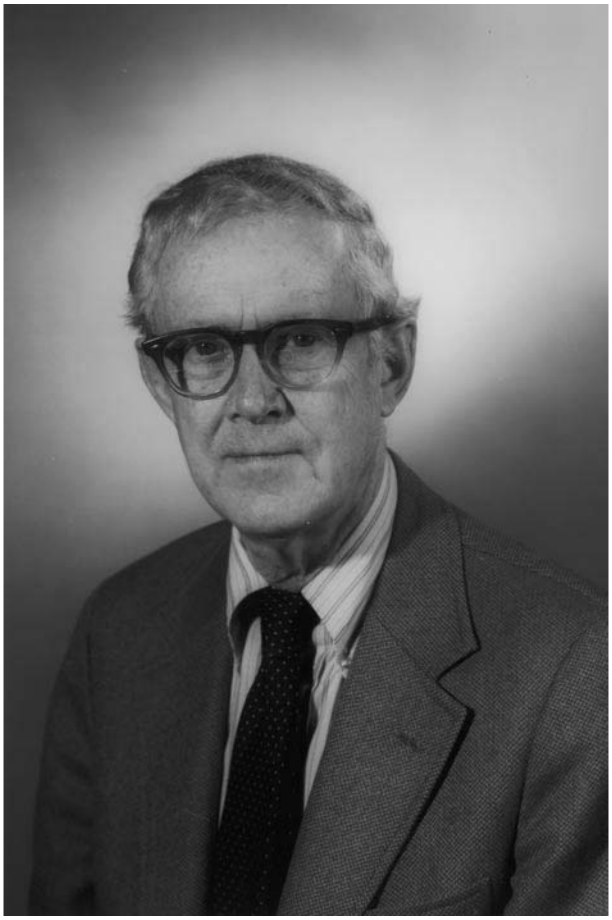
Purcell, Edward Mills

Born **Taylorville, Illinois, USA, 30 August 1912**
Died **Cambridge, Massachusetts, USA, 7 March 1997**



American experimental physicist Edward Purcell is honored within astronomy for the 1951 discovery, with his student Harold C. Ewen, of the 21-cm line of neutral hydrogen, which had been predicted in 1944 by Henk C. van de Hulst, but it was for the 1945 discovery of nuclear magnetic resonance [NMR] that he shared the 1952 Nobel Prize in Physics with Felix Bloch, who had demonstrated the same phenomenon at nearly the same time, using a different technique.

Edward Purcell was the son of Elizabeth Mills, a high school Latin teacher, and Edward A. Purcell, the manager of the Taylorville telephone exchange (and later of the Illinois Southeastern Telephone Company). He probably owed some of his laboratory skills to very early familiarity with electrical equipment, including the magnetos of old crank telephones. Purcell earned a BS in electrical engineering at Purdue University in 1933, spent a year as a foreign exchange student at the Institute of Technology in Karlsruhe, Germany, and entered the Physics Department at Harvard University in 1934. He married Elizabeth Busser, who had also been an exchange student in Germany. Purcell received his Ph.D. in 1938 with a thesis on a spherical condenser mass spectrograph, carried out under Kenneth Bainbridge, but was also introduced to the quantum theory of magnetism by John H. van Vleck.

Purcell was appointed an instructor in the Harvard Department of Physics in 1938, rising through the ranks to assistant professor in 1941, associate professor in 1946, full professor in 1949, and the endowed Gerhard Gade University Professorship in 1961. The first, and probably most distinguished, of his Harvard Ph.D. students was Nicolaus Bloembergen (Nobel Prize in Physics, 1981; Gerhard Gade Professor Emeritus and professor of optical sciences at the University of Arizona). He continued to make significant contributions in the area of NMR until about 1955. The Purcells raised two sons, Frank and Dennis.

During World War II, Purcell worked full-time at the Massachusetts Institute of Technology's [MIT] Radiation Laboratory. He headed the Fundamental Development Group responsible for X-band and K-band radar techniques. Purcell contributed to two volumes of the well-known *MIT Radiation Laboratory Series*.

The associate director, I. I. Rabi, arranged numerous discussions and lectures at the end of the war, to assist the scientists at the Radiation Laboratory in their return to physics research and academic life. Purcell, Henry C. Torrey, and Robert V. Pound discussed the transitions of water molecules in the microwave K-band, as well as the nuclear spin magnetic resonance transitions, observed by Rabi and coworkers with molecular beam techniques. They conceived of the idea of looking for NMR in condensed matter. A literature search revealed that C. J. Gorter in the Netherlands had attempted to detect this phenomenon earlier without success. In December 1945, the three MIT scientists demonstrated the proton magnetic resonance at about 30 MHz in a magnetic field of about 7,000 oersted. They had borrowed the large electromagnet used by J. C. Street for cosmic ray research, in a shed adjacent to the Lyman Laboratory of Physics at Harvard.

Somewhat by accident, Purcell had heard of the van de Hulst prediction of a spectral feature produced by neutral hydrogen when the spin of the electron flips from parallel to antiparallel with the spin of the proton, and suggested a search for it to Harold C. Ewen, who was looking for a thesis topic where he could apply his background in microwave engineering. Ewen built a state-of-the-art microwave radiometer, and they put it at the focus of a small horn antenna, pointed at the sky from the top floor of the Lyman Laboratory of Physics. When the Milky Way passed overhead, the effective radiation temperature at 21 cm increased, leading to recognition of the predicted feature on 25 March 1951. Ewen and Purcell shared the 1988 Tinsley Prize of the American Astronomical Society for their discovery. The line is of enormous continuing importance in astronomy, because it enables us to trace out the amounts and motions of the most abundant element in the Universe, even when there are no stars nearby to light it up.

Van de Hulst was visiting Harvard at that time. Together with Professor **Jan Oort** and a microwave engineer C. H. Mueller, he had been working for some time on the same problem. They used a radio telescope antenna in the Netherlands that had belonged to the Germans during World War II. The Dutch group had experienced an experimental setback caused by a fire. When van de Hulst notified the group of the discovery at Harvard by Ewen and Purcell, they were quickly able to confirm it. Purcell asked the editor of the magazine *Nature* to postpone the publication of the letter he and Ewen had submitted, so that the results of the Dutch group could appear simultaneously. Purcell also had correspondence with Australian radio astronomer **Joseph Pawsey**, so three short announcements appeared in *Nature* **168**, 356 (1951) at the same time.

Purcell remained interested in astronomy to the end of his career, working on the properties of interstellar dust particles in the 1960s and 1970s and on the orientation of rotating dust grains in the magnetic field of interstellar space with **Lyman Spitzer, Jr**.

His wide-ranging intellectual curiosity is evident from two other scientific explorations outside the field of astronomy. He spent considerable time in the search for the magnetic monopole postulated by **Paul Dirac**. Purcell told the author that his unpublished notes on this subject would read like a fable "Hunt for the Unicorn." No evidence for the existence of the magnetic monopole has been found to date.

Purcell's interest in bacterial locomotion met with much more success. It was the result of collaboration with Howard C. Berg, who had been a junior fellow in the Society of Fellows at Harvard, while Purcell was a senior fellow. Berg demonstrated that *E. coli* bacteria move not by a reciprocal motion of their flagella (tails), but rather by a helical twisting motion. Purcell realized that viscous forces completely dominate inertial effects. It is the hydrodynamic regime of low Reynolds number. His paper and popular talk "Life at Low Reynolds Number" bear witness to his superb teaching ability and physical insight. Berg and Purcell received the biological Physics Prize of the American Physical Society in 1984.

In addition to undertaking wide-ranging research, Purcell was an outstanding teacher, receiving the 1968 Oersted Medal of the American Association of Physics Teachers and writing an outstanding textbook on electricity and magnetism and a series of short articles illustrating order-of-magnitude (envelope back) calculations of many different physical phenomena. He was a member of the Science Advisory Board for the US Air Force and of the Presidential Science Advisory Committee [PSAC] under presidents Eisenhower, Kennedy, and Johnson. Purcell received the National Medal of Science in 1969, and was elected to the United States National Academy of Sciences, the American Philosophical Society, and the Royal Society (London) as a foreign honorary member. He served as president of the American Physical soceity in 1969.

Nicolaas Bloembergen

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Pythagoras

Born **Samos, (Greece), *circa* 570 BCE**
Died **Metapontum or Croton (Crotone, Calabria, Italy), *circa* 480 BCE**

Pythagoras was a curious combination of a charismatic guru and mathematical genius, who founded an influential movement characterized by belief in reincarnation, moral and religious purity, and a predilection for numerical explanation. The Pythagorean doctrine that the nature of things consists in mathematical structure led both to **Plato**'s theory of forms and to Greek astronomers' lasting preference for simple, constant motion.

Born the son of Mnesarchus, a gem engraver, the young Pythagoras traveled widely for many years, acquiring both scientific information and religious lore. He is reported to have heard **Thales** and **Anaximander** and to have studied with Egyptian priests and with the Chaldeans. These undoubtedly encouraged his mathematical and astronomical interests. On the religious side, Pythagoras associated with Zoroasterism or the Magi, was initiated into numerous mysteries, and went into the cave on Mount Ida with Epimenides, a famous Cretan miracle-worker. **Heraclitus**, a champion of the empirical search for natural regularities and despiser of omnivorous polymathy, accused Pythagoras of patching together an idiosyncratic pseudo-wisdom from these eclectic sources.

Returning to Samos when he was about 40 and finding the rule of the tyrant Polycrates disagreeable, Pythagoras immigrated to Croton. An eloquent speaker, he quickly achieved prominence, preaching virtue, self-control, and a simple lifestyle to various audiences, including – contrary to custom – married women apart from their husbands and boys apart from their parents. He established a quasi-religious, quasi-philosophical organization, under whose leadership the city prospered so conspicuously that Pythagoreans rose to power in several neighboring cities. Pythagoreans were divided into a larger body of *acusmatici* (hearers) and a smaller inner circle of *mathematici* (learners) who adopted a moderately ascetic life characterized by mathematical and astronomical research, secret doctrines, abstinence from animal food, communal living, and various purificatory rituals connected with belief in reincarnation. Around 500 BCE Kylon, a rejected applicant to the order, led a coup in which many prominent Pythagoreans were assassinated. Pythagoras escaped, finding refuge in Metapontum. He is variously said to have lived to the age of 80, 90, or 100, and may have returned to Croton.

Although **Diogenes** disputed it, most likely Pythagoras, like Socrates and Jesus, wrote nothing. Because Pythagoreans kept their more innovative doctrines secret and honorifically attributed later discoveries to the founder, identifying a doctrine as Pythagoras's own is highly conjectural. Clearly he instituted a way of life based on a core of distinctive cosmological and anthropological beliefs. Pythagoras is reported to have been the first to call the Universe *kosmos* (although **Anaximander** certainly used the term), meaning that it is an ordered whole. The Universe is not mindless matter but a living god, breathing in the surrounding emptiness. Human souls are alienated portions of the divine world-soul, immortal but repetitively embodied in various forms, including nonhuman species. Pythagoras taught the kinship of all life; accordingly, he regarded the animal sacrifices pervasive in Greek religion as parricidal. Pythagoreans even avoided eating anything that seemed to contain soul, such as fava beans.

Pythagoras, using the monochord, discovered that the musical scale instantiated certain whole-number ratios: the octave (2:1), the fifth (3:2), and the fourth (4:3). Because the integers in these ratios add up to ten, ten was regarded as the perfect number and the key to all mathematical truth. He evidently generalized the idea that music consists of numbers to everything else. (**Aristotle** wrote that the Pythagoreans claimed that all things – perceptible objects, souls, and even moral qualities – *are* numbers.) There are two fundamental principles: limit and unlimited. The cosmos and its contents are products of the imposition of limit on the unlimited, various kinds of thing being distinguished by different numerical formulae. Various qualities, including moral virtues, are just special types of mathematical harmony. Living an orderly, nonviolent, scholarly life insures better rebirths and eventual reunion with the cosmic soul. Pythagoras called this manner of living "philosophy" and himself a "philosopher," originating a sense of those terms subsequently adopted by Plato. Pythagoreans allegedly suppressed the proof that the hypotenuse of a right triangle whose other sides were numbers (*i. e.*, integers) could not be a number, since this anomaly contradicted their thesis that all things, including spatial magnitudes, are numbers. Plato subsequently avoided the problem by constructing the cosmos from geometrical, rather than arithmetical, units.

In applying his seminal discovery to astronomy, Pythagoras imputed musical form, as well as mathematical order, to the heavens. The idea behind the doctrine of the "harmony of the spheres" seems to be that the movements of such huge objects must make sounds; and, as the pitch of a vibrating string varies with its length, the pitch of a celestial object varies with the radius of its orbit. Pythagoras may have assigned the same three ratios he identified for strings to the stars, the Sun, and the Moon. Later Pythagoreans assigned other musical ratios to each of the known planets. We do not hear this celestial music because it is omnipresent and invariant, and our auditory apparatus only detects vibratory change. Obviously, music is temporal, and time itself seems to be a serial order of events. For Pythagoreans, time consists in the repetitive orbitings of the celestial bodies, themselves embodiments of harmonious numerical arrangements. In later Antiquity the "harmony of the spheres" was mostly a curiosity; but Pythagoras's belief that heavenly bodies must move in a constant and mathematically elegant way, despite observational evidence to the contrary, continued to dominate astronomical theory. The centuries-long project of "saving the appearances" of planetary retrograde motion by hypothesizing uniformly rotating nested spheres (**Eudoxus**, Aristotle) or a combination of uniformly rotating deferents and epicycles (**Apollonius**, **Hipparchus**, **Ptolemy**, even **Nicolaus Copernicus**) testifies to the persistence of Pythagoras's preference for uniform motion.

James Dye

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Q

Qabīṣī: Abū al-Ṣaqr ˁAbd al-ˁAzīz ibn ˁUthmān ibn ˁAlī al-Qabīṣī

Flourished **(Iraq), second half of the 10th century**

Qabīṣī, an astronomer and astrologer, came from one of two villages called Qabīṣa in Iraq. He studied **Ptolemy**'s *Almagest* under ˁAlī ibn Aḥmad al-ˁImrānī of Mosul, a mathematician and teacher, and dedicated several works (nos. 2, 3, 4, and 6, as given below) to Sayf al-Dawla, the Ḥamdānid Emir of Aleppo between 945 and 967. Otherwise, details of Qabīṣī's life are little known.

Qabīṣī's extant works are the following:

(1) A commentary on **Farghānī**'s *Kitāb al-fuṣūl* (also referred to as *Kitāb fī jawāmiˁ ˁilm al-nujūm*).
(2) A treatise on the distances and volumes of the planets (*Risāla fī 'l-abˁād wa-'l-ajrām*). This treatise provides distances and volumes for the planets other than those of the Sun and the Moon, which had already been given in the *Almagest*. Qabīṣī's account of Mercury was quoted twice by **Bīrūnī** in his *al-Qānūn al-masˁūdī* (Vol. X, Chap. 6).
(3) Book on the introduction to astrology (*Kitāb al-mudkhal ilā ṣināˁat aḥkām al-nujūm*), comprising five chapters. Qabīṣī's most famous work, this book is preserved in several Arabic manuscripts and in a Latin translation of which there are more than 200 manuscripts as well as 12 editions printed between 1473 and 1521. His text was the main book used in universities in the medieval Latin world where astrology was taught as part of the curriculum in medicine.
(4) A treatise for the examination of astrologers (*Risāla fī imtiḥān al-munajjimīn*). This treatise contains 30 astronomical or astrological questions and answers. Qabīṣī divides astrologers into four categories according to their intellectual level: The complete astrologer; the one who knows facts such as the shape of the celestial sphere but can not prove them; the astrologer who accepts things uncritically, like a blind man – the majority of astrologers fall into this category; and one who does not know anything about astronomy and astrology, relying only upon the operations of instruments.
(5) A work on the conjunction of the planets in the zodiacal signs and their prognostications for the revolutions of the years is attributed to Qabīṣī in Latin (*De coniunctionibus planetarum in duodecim signis et earum pronosticis in revolutionibus annorum*).
(6) A mathematical work in Arabic on numbers.

Qabīṣī wrote several other works that are not extant. We know of them because he refers to them in his surviving works. These include a treatise on the size of the Earth, referred to in (2) and (6) as *Risāla fī masāfat al-arḍ*, part of which is quoted at the end of (6); a book on the explanations of astronomical tables, referred to in (2) as *Kitāb fī ˁilal al-zījāt*; a book on affirming the validity of astrology, referred to in the preface of (3) as *Kitāb fī ithbāt ṣināˁat aḥkām al-nujūm*, which was a response to the criticism of astrology by ˁAlī ibn ˁĪsā, an astronomical instrumentmaker of the 9th century; *Kitāb fī al-namūdārāt*, *i. e.*, a book on the *namūdār*s, the method to fix a person's ascendant when the time of birth is unknown, referred to in the fourth chapter of (3); and a book referred to in the introduction of (4) as *Shukūk al-Majisṭī* (Doubts on the *Almagest*).

Keiji Yamamoto

Alternate name

Alcabitius

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Qāḍīzāde al-Rūmī: Ṣalāḥ al-Dīn Mūsā ibn Muḥammad ibn Maḥmūd al-Rūmī

Born **Bursa, (Turkey), *circa* 1359**
Died **Samarqand, (Uzbekistan), after 1440**

Qāḍīzāde al-Rūmī was known for his works in mathematics and astronomy, which were used extensively as teaching texts. He left his native Bursa, where his grandfather had been a prominent judge and his father an eminent scholar, and traveled to Persia in order to gain a higher level of proficiency in the philosophical and mathematical sciences. His nickname indicates his family's standing (Qāḍīzāde = son of the judge) and his origins (Rūmī = from what had been part of the eastern Roman Empire). He studied with many learned scholars in Khurāsān and Transoxiana, among whom was the famous theologian **al-Sayyid al-Sharīf al-Jurjānī** at the court of Tīmūr in Samarqand. Qāḍīzāde, however, felt that Jurjānī was deficient in the mathematical sciences. After Tīmūr's death, Qāḍīzāde found both a student and a patron in Tīmūr's grandson **Ulugh Beg**, also in Samarqand.

Qāḍīzāde joined a group of scholars in the circle of Ulugh Beg that taught mathematics and astronomy, as well as other sciences. He became the head of the madrasa (school) of Samarqand, and Ulugh Beg often attended his lectures. Qāḍīzāde also became one of the directors of the Samarqand Observatory after the death of **Jamshīd al-Kāshī** in 1429, and he undertook its observational programs assisted by **ʿAlī al-Qūshjī**, who continued the program after Qāḍīzāde's death.

Qāḍīzāde was not known for his innovations or creativity. He was most famous for his commentaries on **Maḥmūd al-Jaghmīnī**'s astronomical compendium entitled *al-Mulakhkhaṣ fī ʿilm al-hay'a al-basīṭa* (1412) and **Shams al-Dīn al-Samarqandī**'s geometrical tract *Ashkāl al-ta'sīs* (completed: 1412); the large number of extant manuscripts of both commentaries indicates their enduring popularity as teaching texts. Therefore, it is not surprising that one also finds supercommentaries on Qāḍīzāde's commentaries written by many scholars–teachers including Sinān Pāshā (died: 1486), **ʿAbd al-ʿAlī al-Bīrjandī** (died: 1525/1526), **Bahā' al-Dīn al-ʿĀmilī** (died: 1621), and Qāḍīzāde's student **Fatḥallāh al-Shirwānī** (died: 1486). All of these individuals continued the tradition established at Samarqand, thereby disseminating the mathematical sciences throughout Ottoman and Persian lands. Also noteworthy is that the marriage of Qāḍīzāde's son to Qūshjī's daughter would eventually sire the famous Ottoman astronomer–mathematician **Mīram Čelebī** (died: 1525).

A number of other astronomical works are sometimes attributed to Qāḍīzāde, including a supercommentary on Ṭūsī's commentary (*taḥrīr*) of the *Almagest* and a treatise on the sine quadrant, but it is not clear which of these are authentic. The ascription of a commentary (*Sharḥ*) on **Naṣīr al-Dīn al-Ṭūsī**'s major astronomical work *al-Tadhkira fī ʿilm al-hay'a* (Biblioteca Medicea Laurenziana or. MS 271) to Qāḍīzāde is certainly not correct; this manuscript is actually an incomplete copy of the commentary by Jurjānī.

Among Qāḍīzāde's mathematical works is a treatise on determining the value of sin 1°, for which he seems to have relied heavily on the work of Kāshī. Qāḍīzāde's only philosophical or theological work is a supercommentary on **Athīr al-Dīn al-Abharī**'s *Hidāyat al-ḥikma*, although he intended to write a refutation of parts of Jurjānī's famous commentary on the Persian ʿAḍud al-Dīn al-Ījī's (*circa*: 1281–1355) *Mawāqif.*

F. Jamil Ragep

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Qāsim ibn Muṭarrif al-Qaṭṭān: Abū Muḥammad Qāsim ibn Muṭarrif ibn ʿAbd al-Raḥmān al-Qaṭṭān al-Ṭulayṭulī al-Qurṭubī al-Andalusī

Flourished **Cordova, (Spain), 10th century**

Qāsim ibn Muṭarrif al-Qaṭṭān may well represent the earliest astronomers in Islamic Spain (al-Andalus) of whom we have knowledge. Though known as a reciter of the Quran (*muqri'*) and traditionalist with the sobriquet *al-shaykh al-ra'īs* (Principal Shaykh), only one of his works is extant, a study of cosmological and astronomical subjects. However, in the biographical dictionaries there is no reference to Qaṭṭān's interest in cosmology or astronomy. From what we know of the lives of his teachers, we can deduce that he was born at the end of the 9th or the beginning of the 10th century. An analysis of Qaṭṭān's work offers only two chronological details: a quotation from **Maslama al-Majrīṭī** and the following statement in the title of the star table: "We found its longitude in the ecliptic in the year 300 of the Hijra" (912–913).

If the attribution is correct, Qaṭṭān's work, entitled *Kitāb al-hay'a* (Book on cosmology), would be the first extant Andalusī treatise on astronomy. The only known manuscript is preserved in the Süleymaniye Library in Istanbul (Carullah Efendi 1279, folios 315r–321v). The work is a compendium of all the Andalusī cosmological and astronomical knowledge of the time and draws upon a variety of traditions. The most prominent is that of eastern Islam, which flourished in the 10th century after successfully combining the old cosmology and astronomy of Greece and India. There are also echoes of an old Latin astrological tradition, still in use in the Iberian Peninsula.

The text consists of 30 numbered and five unnumbered chapters. The unnumbered chapters differ from the others in several aspects and do not seem to belong to the work. The chapters are as follows: 1–8: signs of the Zodiac and lunar mansions; 9–11: planets and cosmographical subjects; 12: stars; 13–16: Moon and Sun; 17–27: subjects related to the calendar, *i. e.*, years, months, days, hours (22 and 23 are devoted to clocks); and 28–30: description of the cosmos, both the superlunary and sublunary world. The other five chapters – the ones without numbering – deal with the Sun, the Moon, and terrestrial latitudes. Some of the chapters that purport to explain the physical structure of the cosmos show a clear dependence on **Aristotle**, while others draw upon **Ptolemy**, in particular on his *Planetary Hypothesis*, which very probably reached the author through the *Kitāb al-aʿlāq al-nafīsa* of the eastern geographer Abū ʿAlī Aḥmad ibn ʿUmar ibn Rustah.

The clocks described are a sundial, the description of which coincides almost word for word with the one found in the *Kitāb al-asrār fī natā'ij al-afkār* (Biblioteca Medicea Laurenziana, MS Misc. Or 152, folio 47r), explicitly attributed to **Ibn al-Ṣaffār**, one of Maslama's disciples. This clock is unlike extant Islamic clocks, although we know of at least two texts that describe a similar instrument (the *balāṭa* described in the *Zīj* by **Ibn Isḥāq al-Tūnisī** and the one in the commentary to the *Mišná* by **Maimonides**). These clocks seem to date back to biblical times. The second one, called *thurayya*, is a "fire clock" because the hours are indicated by the burning of oil. A description of a similar clock is found in a work by a certain Yūnus al-Miṣrī. Qaṭṭān's clock derives from a clock calculated for Baghdad, which probably reached al-Andalus through Tunis, perhaps thanks to the well-known epistolary relationship between Ḥasdāy ibn Shaprut of Cordova, and the Tunisian **Dunash ibn Tamīm**.

The star table contains 16 stars. It is a standard table of the kind that accompanies a treatise for constructing an astrolabe, although, in view of the errors found, it was probably derived from a reading of the coordinates of an instrument calculated for Cordova, namely ecliptic coordinates (longitude and latitude) and the degree of the zodiac that rises with a star and diurnal arc. It is the first star table documented in al-Andalus and is clearly influenced by **Battānī** and Maslama.

In a number of chapters there are signs that the author does not have a thorough understanding of the field. However, the work is important because it demonstrates the emergence of astronomical and cosmological knowledge from a range of traditions in 10th-century al-Andalus, the period in which science was beginning to develop in this area. Although the author is Andalusī, the manuscript is eastern, suggesting that it reached a fairly wide readership. The text is largely nonspecialist and was probably used in the nonscientific circles in which the author undoubtedly moved.

Mercè Comes

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Qaṭṭān al-Marwazī: ʿAyn al-Zamān Abū ʿAlī Ḥasan ibn ʿAlī Qaṭṭān al-Marwazī

Born **Marw (Merv, Turkmenistan), 1072/1073**
Died **Marw (Merv, Turkmenistan), October 1153**

Qaṭṭān al-Marwazī was a prominent scholar of the 11th and 12th centuries, whose only extant work, a treatise on astronomy, entitles him to be ranked among the leading observational astronomers of his age. He was born in Marw, an ancient city in Persia, which had become by then one of the most prosperous cities of Great Khurāsān, a vast and flourishing province on the eastern borders of the Islamic world and home to many outstanding scientists, philosophers, religious scholars, saints, and mystics. At the time Marw had ten large public libraries, one of them housing 12,000 books.

Living in a city with a rich cultural milieu, Qaṭṭān al-Marwazī grew up to become an expert in many fields of science and wisdom. Like other erudite and encyclopedic savants of the Islamic Middle Ages, he wrote books in most areas of knowledge including astronomy, medicine, prosody, engineering, and literature. His writings were regarded highly among the learned circles of Marw. Though well versed in different disciplines, Qaṭṭān al-Marwazī's main occupation was medicine.

Sources describe Qaṭṭān al-Marwazī as a master of Greek sciences and an ardent exponent of Greek philosophy. Being a student of Lawkarī, who himself was a student of Bahmanyār, the most distinguished disciple of **Ibn Sīnā**, Qaṭṭān al-Marwazī belongs to the third generation of scholars who have fully benefited from the Avicennian tradition.

None of Qaṭṭān al-Marwazī's numerous writings, however, have survived save a book on astronomy written in Persian and entitled *Gayhānshenākht* (Knowledge of the Cosmos). According to the author, the book was so titled because "he who understands this book will have a coherent knowledge of the configuration of the cosmos, and its system will be clear to him." The book, however, is not confined to cosmology in the proper sense of the term, but, as is usual for the works of its genre in the Islamic tradition, covers a wider range of subjects such as the configuration of the Earth and certain topics in geography. Therefore, it falls within the context of cosmographical works. Furthermore, the treatise also includes what we usually find in the works dedicated to the calendar and issues related to the "passage of time." The book, therefore, comprises a range of topics from the celestial movements, eccentrics and epicycles, apogees, planetary sectors, the ecliptic, the fixed stars, lunar and solar eclipses, the meridian, and the azimuth to the sizes of the Earth and other planets, chronology, and even some minor hints regarding astrology.

Gayhānshenākht may thus be placed within the corpus of what was known as *hay'a basīṭa*, *i. e.*, plain or simplified astronomy. These works were simplified forms and summaries of astronomy that gave a coherent and unified account of the discipline. The main audience for such works were ordinary, educated people for whom astronomy had a greater appeal than other sciences, in part because of its applications in religious matters, and in part because it dealt with the realm of the unknown. Therefore, despite the fact that Arabic was the prime language of science and letters throughout Islamdom, Qaṭṭān al- arwazī, out of an inner obligation, chose to write a simple and easy-to-understand book on astronomy in Persian for the educated public and for beginners who wished to have a share of the art.

Qaṭṭān al-Marwazī seems to have been involved in other aspects of astronomy. His status as an observational astronomer is well established by the fact that he mentions in several places his engagement with astronomical measurements. Furthermore, Qaṭṭān al-Marwazī claims to have written other books on astronomy, including a *zīj* or astronomical handbook, which requires direct participation of the observer. Nevertheless, his interest was not limited to pure astronomy, a science that in his view "is based on certitude and demonstration" and "into which no discrepancy shall find a way." He shows interest in astrology as well, which for him is "a science of analogy and conjecture." By this, however, Qaṭṭān al-Marwazī does not mean to belittle astrology but rather to place each within its own proper domain, since he promises to write a book on that subject, too.

Despite the very little information available to us about the man and his works, we may conclude that Qaṭṭān al-Marwazī was one of the most prominent scientific figures of his time. In a series of correspondences between him and Rashīd al-Dīn Waṭwāṭ, himself a great literary figure of his age, Rashīd al-Dīn Waṭwāṭ does not fail to acknowledge him as "a scholar for whom not even a minute replica can be found across either east or west" even though the author is being accused by Qaṭṭān al-Marwazī of plundering his library. Furthermore, his stature as a great astronomer may be substantiated by the fact that two centuries later Ibn Taymiyya, a renowned religious scholar in Damascus, singles out Qaṭṭān al-Marwazī's name as someone very skillful in astronomy, while discussing the question of lunar crescent visibility.

A clan of the Turkish Ghuzz (Oghuz) tribe from eastern Asia invaded Marw. Being taken captive, Qaṭṭān al-Marwazī is said to have shouted words of insult at his captors, which led to his tragic death. They tortured him to death by filling his mouth with soil.

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Qian Lezhi

Flourished **China, 5th century**

Qian Lezhi, an astronomer of the Liu-Song dynasty (420–479) of the Southern Dynasties (420–589), made detailed armillary spheres that replicated the motion of the sky. About his life we know nothing except that he was the *Taishiling*, the highest official of the Imperial Bureau of Astronomy and Calendrics.

In 436, by command of the emperor, Qian Lezhi made a copper armillary sphere. Historical materials about the device show that the "armillary" was not a real armillary sphere, but a celestial globe demonstrating the apparent motions of celestial bodies. The device was constructed mainly of rings, with a small sphere in the center representing the Earth. Both diameters of the equatorial and ecliptic rings were 6.08 *chi*. (One *chi* equaled about 24 cm during this period.) The circumference of each ring was 18.26 *chi*. One *du* in the sky – ancient Chinese divided the circle into 365 *du* – corresponded to 0.05 *chi* along the circumference of the rings. There was a polar axis paralleling the rotation axis of the Earth. Semicircular rings representing the longitudes of the lunar mansions connected vertically to the equatorial ring. In the area of the North Celestial Pole, the Big Dipper and pole star were shown, but sources do not mention how they were fixed on the device. It is possible that dots representing the Big Dipper and the pole star appeared at the corresponding places. The Sun, the Moon, and five planets (Venus, Jupiter, Mercury, Mars, and Saturn) were fixed on the ecliptic ring.

Besides this device, there was a clepsydra or waterclock connected to the celestial globe, which was also driven by water from the water clock so that the celestial part of the globe moved synchronously with the rotation of the Earth. Therefore, the device could demonstrate the apparent motion of celestial bodies.

Qian Lezhi's thoughts on the design of the instrument were apparently influenced by astronomers **Zhang Heng**, and especially, Ge Heng (3rd century). Ge Heng made an "armillary sphere," which was actually also a moving celestial globe, with an unmoving sphere representing the Earth installed inside the globe itself.

In 440, Qian Lezhi made another, smaller "armillary sphere" that was 2.2 *chi* in diameter. On the surface of the sphere, the lunar mansions and other asterisms were indicated, and the Sun, Moon, and five planets were fixed on the ecliptic. In ancient atlases such as those of **Gan De**, **Shi Shen**, and Wu Xian, the stars were indicated by black dots. Adapting **Chen Zhuo**'s method, Qian Lezhi used white, black, and yellow pear shapes. Some sources say that other color combinations, such as red, black, and white, were used.

Li Di

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Quetelet, Lambert Adolphe Jacques

Born **Ghent, (Belgium), 22 February 1796**
Died **Brussels, Belgium, 17 February 1874**

Lambert Quetelet became one of the most influential social statisticians of the 19th century, but is also remembered for his studies of meteor showers and their apparent radiants.

Quetelet was the son of François-Augustin-Jacques-Henri Quetelet and Anne Françoise Vandervelde. He was educated at the lyceum of his native town. In 1815, when that school was converted to the College of Ghent, he was appointed a professor of mathematics. In 1819 Quetelet was awarded the institution's first Ph.D., for a dissertation on the theory of conic sections. That same year, he was appointed professor of mathematics at the Athenaeum of Brussels, and was soon elected to the Royal Academy of Sciences and Arts. Quetelet was married in 1825; he and his wife had two children.

During the 1820s, Quetelet began a campaign to found an observatory in Belgium. Upon this suggestion, he was commissioned to go to Paris and study the practice of astronomy under **Dominique Arago**, director of the Paris Observatory. While there in December 1823, Quetelet observed a subdivision in the A-ring of Saturn, using the observatory's 10-in. achromatic refractor. He also learned probability theory from Jean Baptiste Joseph Fourier and **Pierre de Laplace**. Belgium's Royal Observatory was not completed until 1833, although Quetelet served as its director after 1828. There, he gave special attention to meteorological and geophysical observations.

Following the very intense Leonid meteor shower of 12/13 November 1833, Quetelet's attention was directed toward the occurrence and annual periodicity of meteor showers. In March 1837, he predicted the return of the Perseid meteors during the coming August. That same year, Quetelet produced the first catalog of historical sightings of this shower. Over time, he amassed more than 300 records of the appearance of this and other suspected meteor showers. Quetelet, however, was not alone in his recognition of the Perseid meteors. Two Americans, Connecticut bookseller **Edward Herrick** and Cincinnati physician **John Locke**, had independently documented the shower's annual nature. Quetelet is also regarded as the codiscoverer of the Orionid and Quadrantid meteor showers.

Quetelet's other astronomical (and meteorological) observations included numerous solar and lunar eclipses, planetary and stellar occultations, the aurora borealis (and its magnetic anomalies), comets, asteroids, and bolides. He determined the longitude difference between Brussels and other European observatories by means of telegraph signals. A catalog of more than 10,000 stars, observed by Quetelet and his associates between 1857 and 1878, was published by his son Ernest in 1887.

Quetelet's most famous work, *On Man and the Development of His Faculties: A Treatise on Social Physics* (1835), laid the foundations of sociology and introduced his concept of the "average man." In 1853, he organized the first international statistics conference and was appointed its president. Toward the end of his life, Quetelet published several histories of the physical and mathematical sciences in Belgium. At the time of his death, he was regarded as Belgium's most revered scholar.

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Qunawī: Muḥammad ibn al-Kātib Sīnān al-Qunawī

Born **Probably Istanbul, (Turkey)**
Died **Istanbul, (Turkey), *circa* 1524**

Muḥammad al-Qunawī, astronomer and *muwaqqit* (timekeeper), lived in Istanbul and pioneered the Turcification movement of the Greco–Hellenic and classical Islamic astronomical literature. Very little is known about his life. However, Qunawī's name indicates that he came from Qunya (Konya, Turkey). Sīnān, his father, served in the Ottoman State Chambers as a scribe, and so he became known as Ibn Kātib Sīnān, *the son of Sīnān the Scribe*.

In his work entitled *Kitāb al-Aṣl al-muʿaddil,* Qunawī states that "he had met all the important astronomers of the time" (Istanbul Archeology Museum, MS 1255/4, 156b). These would have been from among his Ottoman intellectual circle of friends and students who had studied both the astronomical works of **ʿAlī al-Qūshjī**, thus connecting them with the mathematical–astronomical tradition of Samarqand, and the achievements of *ʿilm al-mīqāt* (astronomical timekeeping) of classical Islam, which had reached its apex with the works of **Khalīlī** and **Ibn al-Shāṭir** in 14th-century Damascus.

After completing his education, Qunawī worked for some time as the official *muwaqqit* in several religious institutions including the New (Yeni) Mosque in Edirne. In this capacity, he offered several works in the service of various Sultans: his *Hadiyyat al-mulūk* to Sultan Bāyazīd II, his *Faḍl al-dā'ir* to Sultan Selīm I, and his *Mīzān al-Kawākib* to Sultan Süleymān I (the Magnificent).

Qunawī wrote 11 books on astronomy: seven in Arabic and four in Turkish. Thus his works were not confined to the Turkish-speaking areas of Istanbul, the Balkans, and Anatolia, but could be used in Arabic-speaking areas, such as Cairo, Egypt, as well. Qunawī's works in Turkish provide us with insight into the growing needs of the Ottoman state bureaucracy. In fact, the word *al-Ihkwān* (usually meaning "brothers"), mentioned in the title of his Turkish book *Hadiyyat al-ihkwān,* actually refers to the *muwaqqit*s, who were part of this bureaucracy. Qunawī's Turkish writings helped inculcate an attitude among Ottoman astronomers that contributed to the translation of the Hellenic and Islamic astronomical heritage from Arabic and Persian into Turkish from the beginning of the 16th century onward and paved the way for the Turcification of the language of astronomy.

Most of Qunawī's works were devoted to timekeeping and astronomical instruments. He was thus following one particular tradition of Islamic astronomy whereby it was "in service" to religious, administrative, and social needs of Islamic civilization that placed a high value on precise calculations (dependent upon the mathematical sciences, especially astronomy) and instruments for attaining them. These were used for regulating the prayer times, determining the *qibla* or local direction to Mecca, and ascertaining the beginning and the end of important national and religious days and months (*e. g.*, the month of Ramadan). Each locality needed its own set of tables and calculations, and Qunawī's were for the capital city of Istanbul. Among his achievements, he simplified the standard usage of astronomical instruments, especially quadrants (*al-rubʿ al-mujayyab, rubʿ al-muqanṭarāt*, and *rubʿ al-dā'ira*), and he invented a new method for astronomical calculations in his *al-Aṣl al-muʿaddil.* Qunawī also translated the introductory part of Khalīlī's *mīqāt* tables (which provided solutions to all the standard problems of spherical astronomy for all latitudes) under the title *Tarjamah-i jadāwil-i āfāqī* or *Tarjamah-i risāla fī al-awqāt al-khamsa wa-jadāwil al-raṣad.* To the group of tables that Khalīlī prepared for each degree of latitude, he added a special table for an unknown location at latitude 40° 30′ N.

In the preface to his *Tarjamah-i jadāwil-i āfāqī*, Qunawī says "some of our sons wanted, from this poor man, to learn about sine tables; and so we translated this work into Turkish ..." (Süleymaniye Library, Ayasofya MS 2594, 1b). This is an indication that he was teaching astronomy courses in the *muwaqqithāne*s (timekeeping institutions attached to mosques) and that the language for learning and education was Turkish.

Qunawī's Arabic work entitled *Mīzān al-kawākib* contains time calculation tables by means of stars; the tables have over 500 pages, and include nearly 250 million registers. The main tables show the time from sunset (evening) to sunrise, dawn, and midday for a degree of solar longitude and full vertical rise. One can simply observe a star reaching the last point instantly and also read its rise from a different table prepared by the author; one can enter solar longitude through the rise on the main table and determine the nighttime. According to D. King (1986, p. 248), these tables represent an original Ottoman contribution in determining the astronomical time *via* tables.

After his death, Qunawī's works were developed further by **Muṣṭfā ibn ʿAlī al-Muwaqqit**, the chief astronomer to Sultan Süleymān the Magnificent.

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Qūshjī: Abū al-Qāsim ʿAlāʾ al-Dīn ʿAlī ibn Muḥammad Qushči-zāde

Born **probably Samarqand, (Uzbekistan)**
Died **Istanbul, (Turkey), 1474**

ʿAlī al-Qūshjī was a philosopher–theologian, mathematician, astronomer, and linguist who produced original studies in both observational and theoretical astronomy within 15th-century Islamic and Ottoman astronomy. He contributed to the preparation of **Ulugh Beg**'s *Zīj* at the Samarqand Observatory, insisted on the possibility of the Earth's motion, and asserted the need for the purification of all the scientific disciplines from the principles of Aristotelian physics and metaphysics.

Qūshjī was the son of Ulugh Beg's falconer, whence his Turkish name Qushči-zāde. He took courses in the linguistic sciences, mathematics, and astronomy as well as other sciences taught by scholars in the circle of Ulugh Beg. These included **Jamshīd al-Kāshī**, **Qāḍīzāde al-Rūmī**, and Ulugh Beg himself. It has been claimed that he was also taught by **al-Sayyid al-Sharīf al-Jurjānī**; if so, Qūshjī would have been quite young.

In 1420, Qūshjī secretly moved to Kirmān where he studied astronomy (*circa* 1423-1427) with Mollā Jāmī as well as the mathematical sciences. Upon his return to Samarqand *circa* 1428, Qūshjī presented Ulugh Beg with a monograph *(Ḥall ishkāl al-muʿaddil li-l-masīr)* in which he solved the problems related to Mercury; Ulugh Beg was reported to have been quite pleased. Sources say that Ulugh Beg referred to Qūshjī as "my virtuous son" (= "ferzend-i ercümend" [Nuruosmaniye MS 2932, f. 2b]). Indeed, after the death of Qādīzāde, it was Qūshjī whom Ulugh Beg commissioned to administer the observational work at the Samarqand Observatory that was required for his *Zīj* (astronomical handbook). Qūshjī, often referred to as "ṣāḥib-i raṣad" (head of observation), contributed to the preparation and correction of the *Zīj*, but it is unclear to what extent and at what stage. This question becomes especially problematic in view of Qūshjī's criticisms of it, and his pointing out of mistakes, in his *Sharḥ-i Zīj Ulugh Beg* (Commentary on Ulugh Beg's *Zīj*).

Upon Ulugh Beg's death in 1449, Qūshjī, together with his family and students, spent a considerable time in Herat where he wrote his theological work, *Sharḥ al-Tajrīd*, a commentary to **Naṣīr al-Dīn al-Ṭūsī**'s work *al-Tajrīd fī ʿilm al-kalām,* which he presented to the Timurid Sultan Abū Saʿīd. After Abū Saʿīd's defeat by Uzun Ḥasan in 1469, Qūshjī moved to Tabrīz where he was welcomed by the latter. It is said that Qūshjī was sent to Istanbul to settle a dispute between Uzan Ḥasan and Mehmed the Conqueror; after accomplishing the mission, he returned to Tabrīz. However, around 1472, Qūshī, together with his family and students, left permanently for Istanbul either on his own or because of an invitation from Sultan Mehmed.

When Qūshjī and his entourage approached Istanbul, Sultan Mehmed sent a group of scholars to welcome them. Sources say that in crossing the Bosporus to Istanbul, a discussion ensued about the causes of its ebb and flow. Upon arrival in Istanbul, Qūshjī presented his mathematical work entitled *al-Muḥammadiyya fī al-ḥisāb* to the Sultan, which was named in his honor.

Qūshjī spent the remaining two to three years of his life in Istanbul. He first taught in the Ṣaḥn-i Thamān Madrasa (founded by Sultan Mehmed); then he was made head of the Ayasofya Madrasa. In this brief period, Qūshjī educated and influenced a large number of students, who, along with his writings were to have an enormous impact on future generations. He was buried in the cemetery of the Eyyūb mosque.

Qūshjī, especially when compared with his contemporaries such as Kāshī and Qāḍīzāde, was a remarkable polymath who excelled in a variety of disciplines including language and literature, philosophy, theology, mathematics, and astronomy. He wrote works in all these fields, producing books, textbooks, and short monographs dealing with specific problems. His commentaries often became more popular than the original texts, and themselves became the subject of numerous commentaries. Thousands of copies of Qūshjī's works are extant, many of which were taught in the madrasas.

Qūshjī's philosophy of science, which had important repercussions for the history of astronomy, is contained in his commentary to **Ṭūsī**'s *Sharḥ al-Tajrīd.* Besides being one of the most important theological works in Islam, Qūshjī lays down the philosophical principles of his conception of existence, existents, nature, knowledge, and language. As for the mathematical sciences, Qūshjī in general tried to free them from hermetic–Pythagorean mysticism and to provide an alternative to Aristotelian physics as the basis for astronomy and optics. He sought to define body (*jism*) as being predominantly mathematical in character. Qūshjī claimed that the essence of a body is composed of discontinuous (atomic) quantity while its form consists of continuous (geometrical) quantity. When a body is a subject of the senses, it then gains its natural properties (qualifications).

One consequence of Qūshjī's anti-Aristotelian views was his striking assertion that it might well be possible that the Earth is in motion. Here Qūshjī followed a long line of Islamic astronomers who rejected **Ptolemy**'s observational proofs for geostasis; Qūshji, though, refused to follow them in depending on **Aristotle**'s philosophical proofs, thus opening up the possibility for a new physics in which the Earth was in motion. Qūshjī's views were debated for centuries after his death, and he exerted a profound influence on Ottoman–Turkish thought and scientific inquiry, in particular through the *madrasa* and its curriculum. His influence also extended to Central Asia and Iran, and it has been argued that he may well have had an influence, either directly or indirectly, upon early modern European science to which his ideas bear a striking resemblance.

Qūshjī wrote five mathematics books, one in Persian and four in Arabic. His *Risāla dar ʿilm al-ḥisāb* (Persian), written during his stay in Central Asia (along with his enlarged Arabic version of this work, *al-Risāla al-Muḥammadiyya fī al-ḥisāb*), were taught as a mid-level textbook in Ottoman *madrasas*. In these works, in accordance with the principles he laid down in the *Sharḥ al-Tajrīd*, he tried to free mathematics from hermetic–Pythagorean mysticism. As a result, Ottoman mathematics took on a practical character, which hindered traditional studies such as the theory of numbers.

In the field of astronomy, one of Qūshjī's most important contributions is in the observational program for the *Zīj-i Ulugh Beg* and in his corrections to the work, both before and after publication. In addition, he has nine works on astronomy, two in Persian and seven in Arabic. Some of them are original contributions while others are pedagogical. In his theoretical monograph entitled *Ḥall ishkāl al-muʿaddil li-l-masīr*, Qūshjī criticizes and corrects opinions and ideas pertaining to Mercury's motions mentioned in Ptolemy's *Almagest*. Another work is his *Risāla fī anna aṣl al-khārij yumkinu fī al-sufliyayn* that deals with the possibility of using an eccentric model for Mercury and Venus, which, as he says, goes against both Ptolemy and **Quṭb al-Dīn al-Shīrāzī**.

Qūshjī's *Risāla dar ʿīlm al-hay'a* (Persian), written in Samarqand in 1458, was commonly used as a teaching text; there exist over eighty manuscript copies of it in libraries throughout the world. It was also translated into Turkish. Two commentaries were written on it, one by **Muṣliḥ al-Dīn al-Lārī**, the other by an anonymous author. Lārī's commentary was widely taught in Ottoman *madrasas*. Qūshjī's *Risāla* was also translated into Sanskrit and thus represents the transmission of Islamic astronomy to the Indian subcontinent. Qūshjī wrote an enlarged version of the work in Arabic under the name *al-Fatḥiyya fī ʿilm al-hay'a,* which was presented to Sultan Mehmed in 1473. This work was taught as a middle-level textbook, and was commented on by Gulām Sinān (died: 1506) and Qūshjī's famous mathematician-astronomer great-grandson **Mīram Čelebī**. It was also translated into Persian by Muˁīn al-Dīn al-Ḥusaynī and into Turkish by Seydî Ali Reîs. In the *Risāla* and the *Fatḥiyya*, Qūshjī followed the principles he had laid down in his *Sharḥ al-Tajrīd* and excluded an introductory section on Aristotelian physics that had customarily introduced almost all previous works of this kind.

İhsan Fazlıoğlu

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Quṣṭā ibn Lūqā al-Baˁlabakkī

Born **Baˁlabakk, (Lebanon), probably *circa* 820**
Died **(Armenia), probably *circa* 912–913**

Quṣṭā ibn Lūqā (Constantine, son of Loukas), a scholar of Greek Christian origin working in Islamic lands in the 9th century, did work in astronomy that included translations of Greek astronomical works and original compositions. In addition, he composed and translated mathematical, medical, and philosophical works. Quṣṭā's scholarly reputation extended far and wide, and he was noted for his scientific achievements (especially in medicine, where his authority surpassed **Ḥunayn ibn Isḥāq** according to the bibliographer Ibn al-Nadīm [died: *circa* 990]). He reportedly collected Greek scientific manuscripts from Byzantine lands; his translations and revisions of these formed an important part of his scholarly activities. Qusṭā was fluent in Greek (as well as Syriac), as demanded by his scientific translations, and he also mastered Arabic, a language in which he produced many original scientific compositions. Quṣṭā's scholarly career, which was centered in Baghdad, is notable for his association with numerous patrons, who are particularly important for establishing his biography as well as the chronology of his work. These include various members of the ˁAbbāsid caliphal family, government officials, and a Christian patriarch; the most likely interpretation of the evidence places the bulk of his work in the second half of the 9th century.

The scientific works of Qusṭā include several astronomical compositions, which cover both the theoretical and the practical aspects of astronomy. The best known are:

(1) *Kitāb fī al-ˁamal bi-ʾl–kura al-nujūmiyya* (On the use of the celestial globe; with some variations as to title), which contains 65 chapters and was widely disseminated through at least two Arabic recensions as well as Latin, Hebrew, Spanish, and Italian translations;
(2) the extant astronomical work, *Hayʾat al-aflāk* (On the configuration of celestial bodies; Bodleian Library MS Arabic 879, Uri, p. 190), which is one of the earliest compositions in theoretical (*hayʾa*) astronomy;
(3) *Kitāb al-Madkhal ilā ˁilm al-nujūm* (Introduction to the science of astronomy – astrology);
(4) *Kitāb al-Madkhal ilā al-hayʾa wa-ḥarakāt al-aflāk wa-ʾl-kawākib* (Introduction to the configuration and movements of celestial bodies and stars);
(5) *Kitāb Fī al-ˁamal bi-ʾl-asṭurlāb al-kurī* (On the use of the spherical astrolabe; Leiden University Library MS Or. 51.2: *Handlist*, p. 12); and
(6) *Kitāb Fī al-ˁamal bi-ʾl-kura dhāt al-kursī* (On the use of the mounted celestial sphere).

The two introductory astronomical titles (3 and 4), reported in the lists of Ibn al-Nadīm's *Fihrist* and Ibn Qifṭī (died: 1248), respectively, are not extant, unless the latter is the same as the theoretical work mentioned in (2). F. Sezgin suggests that these two works are the same; however, they are listed as two distinct titles by Ibn Abī Uṣaybiˁa (died: 1269). Work (5) is sometimes questioned as a work by Qusṭā but seems to represent a variation in title of (1). Although E. Wiedemann (1913) treats (6) as an independent work, it also seems to be a variation in title of (1). This leaves Qusṭā with at least four distinct astronomical compositions, two of which (1 and 2) are extant.

Qusta's works also include translations of the so called Little Astronomy or "Intermediate Books" (*Kutub al-mutawassiṭāt*), texts studied after Euclidean geometry in preparation for Ptolemaic astronomy. Extant among these are the Arabic versions of **Theodosius**'s *Spherics* (*Kitāb al-Ukar*) and **Autolycus**'s *Rising and Setting* [*of Fixed Stars*] (*Kitāb al-Ṭulūˁ wa-ʾl-ghurūb*). In addition to other extant translations, such as Hero of Alexandria's "On the Raising of Heavy Objects" (*Fī rafˁ al-ashyāʾ al-thaqīla*), Qusṭā is associated with Arabic versions of **Aristotle**'s *Physics* as well as the later commentaries of Alexander of Aphrodisias and **Philoponus** on certain of their books. This dual translation program fits well with his statements about the "cooperation" of natural philosophy and geometry in optics as a mixed mathematical science, a genre to which astronomy and mechanics also belong.

Elaheh Kheirandish

Alternate name

Costa ben Luca

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R

Rāghavānanda Śarman

Flourished **Rāḍha, Bengal, (India), 1591–1599**

Rāghavānanda Śarman was a Brāhmaṇa who followed the Saurapakṣa school of astronomy. He composed several astronomical works in the late 16th century, including the *Viśvahita*, a set of astronomical tables whose epoch is 1591; the *Dinacandrikā*, another set of astronomical tables whose epoch is 1599; and the *Sūryasiddhāntarahasya*, a commentary on the *Sūryasiddhānta*, written in 1591. Little is known of these three works though they have been published.

Setsuro Ikeyama

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Raimarus Ursus

➤ **Bär, Nicholaus Reymers**

Rainaldi, Carlo Pellegrino

➤ **Danti, Egnatio**

Ramée, Pierre de la

➤ **Ramus, Peter**

Ramus, Peter [Petrus]

Born **Cuts, (Oise), France, 1515**
Died **Paris, France, 26 August 1572**

Peter Ramus rejected scholasticism and outlined new ways to view and to teach knowledge, influencing astronomy's transition from medieval to modern form. He was born in an impoverished noble family originally from Liège. There appears to have been little that was unusual about Ramus's early education. At around 12, after two unsuccessful attempts to enter the University of Paris, he enrolled at the Collège de Navarre, where he earned money working as a servant to wealthier peers. Having to attend school as a day student, however, meant that Ramus did not complete his master of arts until he was 21. Of special benefit was the friendship that Ramus then forged with his later patron, Charles de Guise, who was to become Cardinal of Lorraine and, eventually, of Guise. The support of Guise disappeared after Ramus's conversion to Protestantism around 1562, but the long and active intervention of the cardinal on Ramus's behalf was responsible for much of the fame he gained during his life.

Ramus's career began sedately enough as an instructor at the Collège du Mans, but he soon moved, with his longtime collaborator in rhetoric, Omer Talon, to the Collège de l'Ave Maria, also in Paris. There, in 1543, Ramus published the first of many attacks on Aristotelian and scholastic education that would make him notorious and that led directly or indirectly to his death. Ramus's assertion that the medieval approach to learning, with its long tradition of minutely analyzing and carefully commenting on selected classical authors, was bankrupt proved scandalous to the faculty of Paris, and in short order they secured a ban on his teaching of dialectic (the rhetorical practice of logical principles).

This edict simply led Ramus to concentrate his efforts on the instruction of eloquence and mathematics. He was forced to teach himself the latter subject, since it had been minimal in his university curriculum. But taken together, the two apparently disparate disciplines reveal exactly how much of Ramus's work remains entrenched in premodern modes of thought. To Ramus, the study of numbers and the study of literature were but two aspects of one unified and coherent body of knowledge, which in all its facets was directed only at "disputing well," as he put it in his 1543 *Structure of Dialectic*.

The prospects of Ramus began to improve in 1545 when he was invited to become an instructor at the more prestigious Collège de Presles, where Talon again joined him. Ramus was shortly thereafter promoted to principal of the school and in 1547, following the succession of Henry II to the throne and the subsequent elevation of Charles de Guise in the estimation of the court, all restrictions on Ramus's teaching were lifted; he was left entirely free to comment on the whole range of university subjects. In 1551, he was made a *regius* professor of eloquence and philosophy – the only time these two fields were combined under one title. In 1565, he was chosen dean of the *regius* professors, who came collectively to be called the Collège de France and who, as a body, had been intended by Francis I to represent a humanistic alternative to the resolutely scholastic education of the University of Paris. After this, his fortunes began to decline, falling slowly at first and then precipitously. Suspected even in the late 1550s of being a secret Protestant, Ramus had to flee Paris for Fontainebleau under royal protection during the religious troubles of 1562. He returned in 1563, but having made his conversion public in the intervening year, Ramus entered the city this time without the critical support of Guise. Harried by a growing number of antagonists, Ramus left Paris again in 1567 and again took refuge with a sympathetic member of the royal family.

From 1568 to 1570, Ramus toured the prominent Protestant centers of learning in Germany and Switzerland. During these years, too, he began to broaden his vision of pedagogical reform and wrote on subjects ranging from theology to astronomy. He found the academic atmospheres of Heidelberg and Geneva, though, uncertain at best and returned to Paris for the last time in 1570. The royal family, especially the queen mother, continued to defend Ramus publicly, but he was murdered during the Saint Bartholomew's massacre.

Ramus does not very directly affect the history of astronomy, but his work was influential throughout the 17th and 18th centuries in Europe and America in a surprising number of ways. The topical organization of many modern encyclopedias can be traced to his interest in systematic thought, and **Francis Bacon**'s search for an inductive method is in part attributable to his own youthful interest in Ramus's writing. Primarily, Ramus advocated a regular approach to the study of any given subject. He believed that all realms of knowledge could be construed schematically, and that any discipline of learning would conform to three "laws" of universality, homogeneity, and generality. In other words, a "natural method" of learning would be observably true in every posited application of the art or science, specific in its description, and arranged in such a way as to exhibit the general truths on which it was based.

Ramus considered astronomy a branch of physics and, as such, part of the quadrivium of the university curriculum. Characteristically, he did develop a chart of physics, in which the stars (still very much after the manner of **Aristotle**) were classed as elements of constant simple matter, opposed to the immaterial essences of God and intelligence. Beyond this, Ramus seems merely to have appreciated astronomy as an application of mathematics, though he was critical of both **Nicolaus Copernicus** and **Ptolemy** for propounding their respective theories of the Solar System without observation. Copernicus thus had violated the first law of method. It is, in the end, one of the most telling marks of Ramus's influence that **Johannes Kepler** later claimed, with evident pride, that his own work had at last satisfied the demands of Ramus on astronomy.

H. Clark Maddux

Alternate name

Ramée, Pierre de la

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Raṅganātha I

Flourished **Kāśī, (Vārānasi, Uttar Pradesh, India), 1603**

Raṅganātha I was born into a family of astronomers; his father was Ballāla. Raṅganātha I wrote a popular Sanskrit commentary, the *Gūḍhārthaprakāśikā* (1603), on the anonymous *Sūryasiddhānta* (10th or 11th century), one of the most popular astronomical works in Sanskrit. Raṅganātha I's son, Munīśvara, was also an astronomer and composed a Sanskrit astronomical treatise, the *Siddhāntasārvabhauma* (1646), along with a commentary on the *Siddhāntaśiromani* of **Bhāskara II**.

The *Sūryasiddhānta* was the fundamental text of the Saura School, one of four principal schools of astronomy active during the Hindu classical period (late 5th to 12th centuries). Those editions of the *Sūryasiddhānta* that have come down to us, including the first English translations, are mostly based on Raṅganātha I's text, and so have acquired considerable influence.

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Rañganātha II

Flourished **Kāśī, (Vārānasi, Uttar Pradesh, India), 1640 or 1643**

Rañganātha II was born into a rival family of astronomers sharing the same name as **Rañganātha I**; his father was Nṛsiṃha. He wrote a Sanskrit astronomical work, the *Siddhāntacūdāmaṇi* (1640 or 1643), along with a number of other astronomical and mathematical works. Rañganātha II's father had written a commentary on the anonymous *Sūryasiddhānta* (10th or 11th century). Rañganātha II's brother, **Kamalākara**, likewise composed a Sanskrit astronomical treatise, the *Siddhāntatattvaviveka* (1658).

The *Siddhāntacūdāmaṇi* consists of 12 chapters and covers many of the standard topics discussed in Hindu astronomy of the classical period (late 5th to 12th centuries). It is also based on the *Sūryasiddhānta*.

Rañganātha II also composed the *Bhañgīvibhañgīkaraṇa*, a detailed work on the theory of planetary motions that criticized an earlier work of Munīśvara, son of Rañganātha I. Rañganātha II's astronomical writings included the *Lohagolakhaṇḍana*, a work on the celestial sphere, and the *Palabhākhaṇḍana*, a guide to determining terrestrial latitudes from observations of the stars.

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Rankine, William John Macquorn

Born **Edinburgh, Scotland, 5 July 1820**
Died **Glasgow, Scotland, 24 December 1872**

Scottish railroad engineer William Rankine, among many other activities ranging over science and engineering, wrote down in 1869 a set of equations connecting the density, pressure, and temperature of gases on the two sides of a shock wave. These were generalized in 1887 by Pierre Henri Hugoniot (1851–1897) and, in the form of the Rankine–Hugoniot relations, can be used to describe, for instance, propagation of a supernova remnant moving into the interstellar medium at a speed faster than that of sound.

Virginia Trimble

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Ranyard, Arthur Cowper

Born **Swanscombe, Kent, England, 21 June 1845**
Died **London, England, 14 December 1894**

Arthur Ranyard not only observed the features of the Sun but also interpreted other solar observations in order to understand the sun's physical characteristics. He moved to London at an early age, and studied mathematics at University College, London, and Pembroke College, Cambridge. As a student, Ranyard and George de Morgan (son of **Augustus de Morgan**, the well-known mathematician) played a leading role in the founding of the London Mathematical Society. After taking a Cambridge law degree, Ranyard was called to the Bar at Lincoln's Inn, and practiced as a barrister for the rest of his life. He became a member of the Royal Astronomical Society in 1863, and served as its secretary in 1873.

Despite his success at law, astronomy was always Ranyard's avocation and true passion. He was especially interested in the Sun, and his diligence and high intelligence helped him rise quickly above the level of a *dilettante*. He traveled, at his own expense, to view several solar eclipses, including one in 1870 viewed from Sicily, and another in August 1878 from Cherry Creek (near Denver), Colorado, USA, which Ranyard observed with **Charles Young**'s party. The next year, he published his most important work on solar eclipse observations.

On the basis of his comprehensive review of historical eclipse observations, Ranyard discovered that the form of the extended and much-attenuated outer atmosphere of the Sun, the corona, varied with the sunspot cycle. As **Agnes Clerke** put it:

> "When sun-spots are numerous, the corona appears to be most fully developed above the spot-zones, thus offering to our eyes a rudely quadrilateral contour. The four great luminous sheaves forming the corners of the square are made up of rays curving together from each side into 'synclinal' or ogival groups, each of which may be compared to the petal of a flower."

At sunspot minima, the corona has a more shapeless, roughly circular, and amorphous appearance.

Ranyard mounted another expedition to Sohag, in Upper Egypt, for the eclipse of 17 May 1882. Totality lasted only 74 s, but was memorable because of the unexpected appearance of the solar-eclipse comet X/1882 K1, seen and photographed during the eclipse and never seen again.

Yet Ranyard was not primarily an observer; rather, he was a keen student of historical records made by others. His analysis of these observations was frequently highly perceptive and produced new results or cleared up long-standing enigmas. For instance, he and **John Hind** independently debunked the notion, based on a single drawing by the German amateur Johann Pastorff, that the great comet C/1819 N1 had been visible in transit in front of the Sun.

His work on periodicities related to the sunspot cycle led him to take an interest in Jupiter. Its cloud markings were subject to occasional outbreaks; were these related, possibly, to the sunspot cycle? Ranyard was a member of a group organized in March 1876 by the Royal Astronomical Society for the study of Jupiter. (Other members included **William Huggins**, William Noble, Alexander Lindsay, **Laurence Parsons**, and **Thomas Webb**.) Ranyard concluded from examining all the observations then available that deeper tinges of color and the eruption of equatorial "porthole" markings seemed more likely to appear during years of sunspot minima. This was a pioneering effort, based on insufficient data; unfortunately, it has not been borne out by modern studies.

After the death of the prolific astronomy popularizer **Richard Proctor** in 1888, Ranyard produced revised editions of some of Proctor's works, such as his *Old and New Astronomy*, and became editor of *Knowledge*, a London illustrated scientific magazine that had been founded by Proctor. In this role, he introduced large-scale photogravure reproductions of astronomical photographs, including reproductions of many of **Edward Barnard**'s pioneering wide-angle photographs of the Milky Way obtained at Lick Observatory, California, USA, with the Willard portrait lens. In commenting on the wild and mysterious dark markings revealed in these photographs, Raynard first perceived that they were best explained by assuming the existence of masses of dark absorbing matter rather than as holes or gaps in the star clouds. In making this suggestion, he departed from the view that had been hitherto maintained by **William Herschel** and **John Herschel**. It was a major breakthrough, but its time had not yet come. Indeed, Barnard himself continued to struggle with the nature of the dark markings for many years before finally convincing himself that Ranyard's explanation had to be the correct one.

In 1893, Ranyard accompanied Barnard on the latter's triumphant Grand Tour of the Continent following his discovery of the fifth satellite of Jupiter. Barnard found that even when suffering from hay fever, as he did on the train from Boulougne to Paris, Ranyard never lost his politeness. When the two men visited **Camille Flammarion** at Juvisy, Ranyard became so much a part of the occasion that Flammarion remarked that he was "a perfect Frenchman." He was as much appreciated for his personal charm as for his perceptive knowledge of astronomy. Soon after his return from Europe, Ranyard was taken ill. He died of cancer.

William Sheehan

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Rauchfuss, Konrad

Born **Frauenfeld, Thurgau, Switzerland, *circa* 1530**
Died **Strasbourg, (Bas-Rhin), France, 26 April 1600**

Konrad Rauchfuss is best known as a mathematician, and his name is connected with the astronomical clock in the cathedral of Strasbourg.

Petrus Dasypodius, the father of Konrad, was one of the Swiss humanists; he taught at the school of Johannes Sturm in Strasbourg, wrote humanistic treatises, and held lower church positions. His son studied at this academy with Christian Herlinus and became professor there in 1558.

Rauchfuss devoted himself mainly to the teaching of mathematics. He recognized early the low level of knowledge and teaching of mathematics in his time, and he decided to translate into Latin the basic Greek mathematical texts. He edited and commented on works by Euclid, Heron of Alexandria (his favorite author), **Ptolemy**, and then propositions of the works by **Theodosius of Bythinia**, **Autolycus**, and Barlaamo. A remarkable textbook *Analyseis geometricae sex librorum Euclidis* (1566) contains the proofs of the first six books of Euclid's *Elementa*; Rauchfuss wrote it together with his teacher Herlinus. The numerous textbooks of Rauchfuss were in use for many years at many European universities.

Rauchfuss's astronomical clock in the cathedral of Strasbourg replaced the original one from 1352 to 1354. That clock had been taken down about 1550, and nothing was left from it. After several reconstructions and improvements in the following centuries, today's clock still follows the principal design by Rauchfuss, and contains some original parts. The Rauchfuss clock was installed in the cathedral between 1571 and 1574, and Rauchfuss described it in detail in the book *Heron mechanicus* (Basel, 1580). A remarkable portrait of **Nicolaus Copernicus**, painted on the clock by Tobias Stimmer (1539–1582), confirms that Rauchfuss appreciated Copernicus's work, but he never became an adherent of the Copernican cosmological system.

Martin Solc

Alternate name

Cunradus Dasypodius

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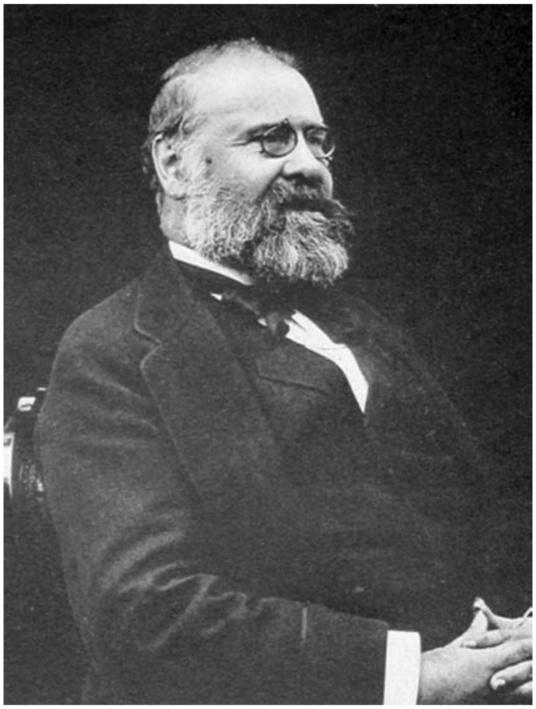
Rayet, Georges-Antoine-Pons

Born **near Bordeaux, Gironde, France, 12 December 1839**
Died **Floirac near Bordeaux, Gironde, France, 14 June 1906**



Georges Rayet was a French astronomer who, with **Charles Wolf** at the Paris Observatory in 1867, detected a class of rare, exceptionally hot stars whose spectra show strong broad emission lines of helium, carbon, and nitrogen. Wolf–Rayet stars, as they are known after their discoverers, are about twice the size of the Sun, and have a rapidly expanding outer shell – the source, it is thought, of the emission lines. The residual hydrogen envelopes of these stars have been stripped away (by stellar winds or mass transfer), revealing their deeper layers. Many central stars of planetary nebulae are of this type.

Rayet had no formal schooling until the age of 14, when his family moved to Paris. He was admitted to the École Normale Supérieure (1859); he graduated with a physics degree in 1862 and taught for a year before obtaining a post in the new weather forecasting service set up by **Urbain Le Verrier** at the Paris Observatory. In 1873, its operation was entrusted to him, but within the year the two men disagreed over storm forecasts, and Rayet was dismissed. He then lectured on physics at the Faculty of Sciences of Marseilles, and in 1876 was appointed professor of astronomy at Bordeaux.

Following a government initiative to build several new observatories, Rayet was asked to undertake a survey of the history and instrumentation of the world's observatories. He was subsequently offered the directorship of the observatory to be built at Floirac. From 1879, he held this position in tandem with his Bordeaux appointment. Having installed modern astrometric equipment at Floirac, Rayet organized a program of positional measures of stars, nebulae, and the components of binary systems.

Rayet's first collaboration with Wolf occurred in 1865 when they photographed an eclipse of the Moon. On 20 May of the next year, the pair noted bright emission lines, widened into bands, in the continuous spectrum of a nova (T Coronae Borealis, the first nova to be examined spectroscopically). In the following year, they made the observations that would immortalize their names in the Wolf–Rayet stars, when they discovered a similar appearance in the spectra of three eighth magnitude stars in Cygnus.

In 1868, Rayet undertook responsibility for the spectroscopic work on an expedition to the Malay Peninsula to observe a total eclipse of the Sun. With Wolf, Rayet also made significant observations of comet C/1874 H1 (Coggia), and observed the total solar eclipse of 1905 from Spain. He was an enthusiastic supporter of the International *Carte du Ciel* Astrographic Chart and Catalogue, and in the year before his death published the first volume of the *Catalogue photographique de l'Observatoire de Bordeaux*.

Richard Baum

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Raymond of Marseilles

Flourished **(France), 1141**

Raymond was among the earliest Latin scholars to adapt Arabic science to the needs and requirements of a well-educated Latin-reading public. While not making translations himself, he was well acquainted with Arabic texts translated in Toledo, in the fields of astronomy, astrology, and probably alchemy.

The works that can be securely attributed to Raymond are three substantial texts that refer to each other. The first is *Liber cursuum planetarum*, an adaptation to the meridian of Marseilles of the astronomical tables originally drawn up for the meridian of Toledo and translated from, or based on, Arabic sources. Raymond's adaptation was made in 1141 and is accompanied not only by his own explanation on how to use the tables (*regula*), but also by a long essay justifying the study of astronomy and, in particular, astrology. This essay begins with a substantial poem, and the essay itself quotes liberally from classical sources and the church fathers. The second work is *Liber iudiciorum*, a handbook of judicial astrology, based on 12th-century translations from Arabic of astrological works by **Abu Maʿshar, al-Qabisi**, and Sahl ibn Bishr, and on earlier Latin material attributed to "Argaphalau" and **Ptolemy**. The third is *Liber de astrolabio*, a text on the construction and use of the astrolabe.

Raymond was not an innovator, and his astronomical and mathematical competence is not outstanding. Nevertheless, his work had considerable influence in the 12th century, especially in England, where a version of the *Liber iudiciorum* was prepared for Robert, Duke of Leicester, and where **Roger of Hereford** adapted the tables of Marseilles for his local meridian.

Charles Burnett

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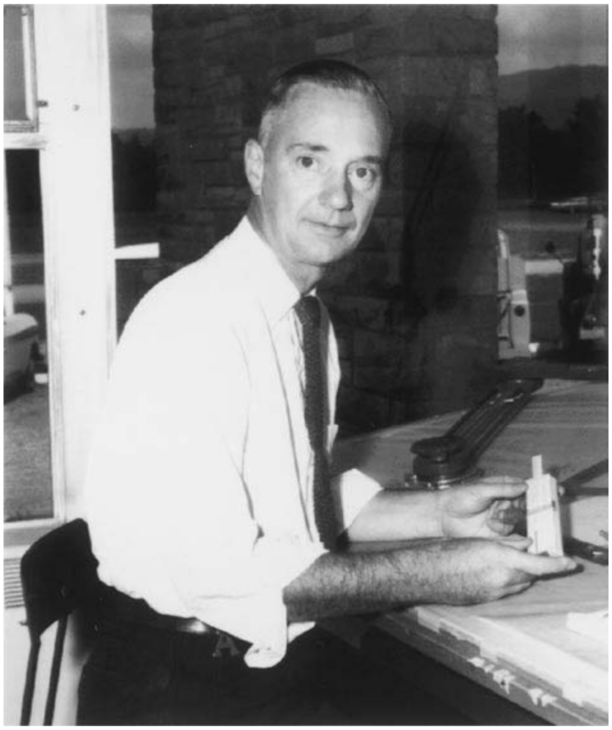
Reber, Grote

Born **Chicago, Illinois, USA, 22 December 1911**
Died **Tasmania, Australia, 20 December 2002**

Grote Reber was the first person who knowingly built a radio telescope. With it, Reber pioneered the exploration of the sky at radio wavelengths, locating the first known discrete radio objects, Cygnus A and Cassiopeia A.

Reber's father, Schuyler Colfax Reber was a lawyer and part owner of a canning factory, while his mother, Harriet (*née* Grote) Reber taught elementary school where Grote grew up in Wheaton, Illinois, a suburb of Chicago. Among Harriet's pupils in the seventh and eighth grade at the Longfellow school in Wheaton was **Edwin Hubble**, with whom Reber later corresponded. At the time of his graduation with a BA in electrical engineering from the Armour (now Illinois) Institute of Technology in 1933, Reber was already interested in **Karl Jansky**'s 1932 discovery of radio emission from our Galaxy. Reber sought employment at the Bell Laboratories, Holmdell, New Jersey, in order to work with Jansky. Unsuccessful in that strategy, Reber accepted employment with various manufacturers of electronic equipment in the Chicago area.

After failing to interest others in his plans to follow up on Jansky's work, Reber, an amateur radio enthusiast (call letters W9GFZ), decided to build his own dish antenna in order to achieve a higher angular resolution than that of Jansky's rather broad-beamed rotating antenna. Jansky made observations at a wavelength of 14.6 m (a frequency of 20.53 MHz). Reber realized that observing at a higher frequency would also facilitate a higher angular resolution and, if the radiation was of thermal origin, stronger signals.



Reber financed and designed the telescope himself and, with little assistance, constructed it in the 4 months from June to September 1937 at his mother's home. The telescope, a meridian transit instrument consisting of a wooden frame with a galvanized iron reflecting surface 9.6 m in diameter with a focal length of 6.1 m, was able to observe declinations between −32.5° and +90°. Reber also designed and built the antenna feeds and receivers; his work as an engineer for radio manufacturing firms in Chicago gave him access to state-of-the-art technology.

Reber first observed in 1938 at a wavelength of 9 cm (3,300 MHz), close to the shortest wavelength possible at the time, and then with a more sensitive receiver at 33 cm (910 MHz) in late 1938 and early 1939. Observations of various parts of the Milky Way, the Sun and other bright stars, and planets were unsuccessful, which, as Reber characteristically put it, was "rather dampening to the enthusiasm." His lack of success did, however, indicate that the radio emission was not thermal. It is now known that radio emission at centimeter and meter wavelengths is predominantly produced by synchrotron radiation.

Reber designed a new receiver to operate at 187 cm (162 MHz). Early observations with this receiver suffered from human electrical interference, primarily automotive ignitions. To minimize these problems, Reber worked during the day, slept in the early evening, and observed after midnight. By early April 1939, it was clear that Jansky's cosmic static was coming from the Galaxy. The trend of stronger emission near the galactic center seen by Jansky was confirmed, but Reber's efforts to detect individual celestial objects including the Sun were not successful.

Reber's results, like Jansky's before him, were readily accepted for publication in the *Proceedings of the Institute of Radio Engineers*. Reber also submitted his results to the *Astrophysical Journal*; however the editor, **Otto Struve,** accepted Reber's paper only after astronomers from the University of Chicago visited Wheaton to inspect his equipment. Even then, when Reber's paper was published in 1940, the section considering theoretical aspects of his results was removed!

After Reber improved the sensitivity of his receiver, his survey of the sky undertaken between early 1943 and mid-1944 confirmed that diffuse radio emission came from the galactic plane, but that there were also several peaks of emission: one in Cassiopeia, which is now known to be the galactic supernova remnant Cassiopeia A, and a broader peak in Cygnus, later resolved into the radio galaxy Cygnus A and the galactic Cygnus X complex. Observations of the Sun in September 1943 found it to be an intense source of radio emission. Reber's 1944 papers in the *Proceedings of the Institute of Radio Engineers* were the first published reports of radio emission from the Sun; he was unaware of classified earlier detections of the Sun during the war of which that by **James Hey** is best known. Reber found that near the maximum of the 11-year solar cycle, the Sun was not only very bright at radio wavelengths but, as a series of observations at 62.5 cm (480 MHz) from mid-1946 onward revealed, it was also the source of intense, short-lived bursts of radio emission.

News of Reber's discoveries reached the Dutch astronomer **Jan Oort**, who was one of the few who fully appreciated their significance. Oort realized that radio observations, unlike optical observations, did not suffer from obscuration caused by dust and gas, and would provide a powerful probe if a spectral line at radio wavelengths could be found. Oort assigned the problem to Hendrik van de Hulst, who discovered that neutral hydrogen had a potentially detectable hyperfine transition at 21 cm (1400 MHz). Van de Hulst met Reber in 1945, and while it was not clear that the line would be detectable, Reber started preparing his telescope to observe at that frequency.

In 1947, Reber accepted a position with the National Bureau of Standards [NBS] in Washington; his work in Wheaton came to an end. Reber moved his telescope to Sterling, Virginia, and then in 1959 moved it again to the National Radio Astronomy Observatory at Green Bank, West Virginia, where it remains to this day. The telescope now sits on an azimuth rail that had been designed and built but never installed in Wheaton. Reber attempted to generate interest in his design for a 220-ft. (67-m) radio telescope, but was again ahead of his time. The United States' interest in radio astronomy lagged behind Australia's, the Netherland's, and the United Kingdom's.

In 1951, Reber left the NBS and moved to Hawaii. This move marked the beginning of his long association with Research Corporation, a private foundation for the advancement of science established in New York in 1912. Reber installed antennas on the 10,020-ft. summit of the Haleakala volcano on the island of Maui. There he used the Lloyd's mirror interferometric technique in which a reflection off water acts as the second mirror pioneered by John Gatenby Bolton (1922–1993) and colleagues in Australia. Observations were attempted at frequencies near 20, 30, 50, and 100 MHz. However, anomalies introduced by the ionosphere rendered the first three frequencies unusable. At 100 MHz, the bright radio sources Cas A and Cyg A were detected and considerable asymmetry inferred for both sources from the differences in their rising and setting interferometric patterns.

Having discovered the important role of the ionosphere in low-frequency observations, Reber moved in 1954 to Tasmania, near the south magnetic pole, where ionospheric effects were known to be much smaller. He collaborated with Graeme Reade Anthony "Bill" Ellis (born: 1921) to determine the lowest frequency at which they could detect extraterrestrial radio emission. They were able to observe several times at 0.91 MHz, and on three occasions for half an hour or so at 0.52 MHz during the 1954/1955 solar minimum. Reber then built an array of 192 dipoles covering 223 acres and carried out a survey of the sky between February 1963 and May 1967 at 144 m (2.1 MHz). Reber found that the radio appearance of the sky at these longer wavelengths is the inverse of that at shorter wavelengths, with the sky being brighter at the galactic poles, and darker at the galactic center. Reber's very low frequency observations were confirmed (albeit with lower angular resolution) by observations with the Radio Explorer Satellites in the late 1960s and 1970s. The radio darkening toward the galactic plane is thought to arise from absorption by plasma in our galaxy.

Reber returned to Tasmania in the 1970s after a 4-year stay at the Ohio State University, which had awarded him an honorary Doctor of Science degree in 1962. Reber was also honored with the Henry Norris Russell Lectureship from the American Astronomical Society and the Catherine Wolfe Bruce Award from the Astronomical Society of the Pacific in 1962, the Elliot Cresson Gold Medal from the Franklin Institute in 1963, the Karl G. Jansky Lectureship of the National Radio Observatory in 1975, and the Jackson-Gwilt Medal and Gift of the Royal Astronomical Society in 1983.

The self-professed stubbornness with which Reber persevered through many months of unsuccessful observing in Wheaton also attended his refusal to accept the Big-Bang model of the expanding Universe. He favored an interpretation of redshift in terms of energy loss due to multiple Compton scatterings, although this theory can be readily falsified. However, it was Reber's determination to succeed in spite of initial setbacks that ensured that radio astronomy would develop into a thriving, fundamental field of research, and that opened the door to the possibility of astronomical observation at many other nonvisual wavelengths.

Philip Edwards

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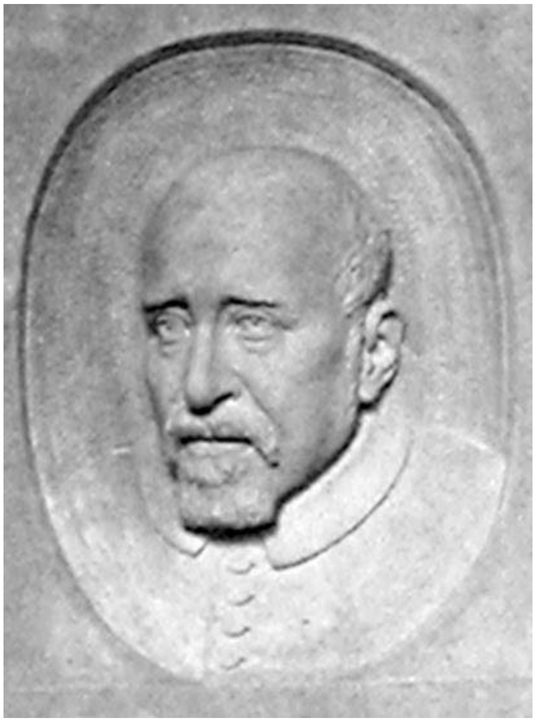
Recorde, Robert

Born **Tenby, (Dyfed), Wales, *circa* 1510**
Died **Southwark, (London), England, 1558**



Robert Recorde was the first writer in English on arithmetic, geometry, and astronomy.

Recorde was the son of Thomas Recorde and Rose Johns (or Jones). He received his BA and was elected fellow of All Souls College, Oxford University, in 1531. Recorde then moved to Cambridge, where he studied mathematics and medicine, and graduated with an MD at the University of Cambridge in 1545. He may have returned to Oxford University to teach mathematics, rhetoric, anatomy, music, astrology, and cosmography, but details are lacking. In fact, it seems that his reputation as a teacher rests on the views expressed in his treatises about how best to teach mathematics. Recorde moved to London where he practiced as a physician from 1547. In 1549 he was comptroller of the Mint at Bristol. The same year he became entangled in political intrigues and was accused of treason by William Herbert; this marked the beginning of a permanent quarrel with Herbert that had serious consequences for Recorde's later career. In May 1551 he was appointed general surveyor of the mines and money by the king. Recorde died in the King's Bench prison for failure to pay a penalty in a libel suit that Herbert had brought against him, yet left a little money to relatives in a will that was admitted to probate on 18 June 1558.

Recorde seems to have been a polymath who collected historical and other ancient manuscripts. His major claim to fame rests on his precociousness in mathematics, and he was the first to introduce algebra into England. Recorde's *Pathway to Knowledge* (1551) contains the first use of the term "sine" in English, and it also has a woodcut portrait of Recorde. He introduced a number of arithmetical symbols into English, and his works in mathematics remained standard authorities until the end of the 16th century.

The *Pathway*, subtitled "First Principles of Geometry," explains solar and lunar eclipses and contains a list of astronomical instruments. The *Castle of Knowledge* (1556) is the first comprehensive treatise on astronomy and the sphere to be printed in English, containing Ptolemaic astronomy in an elementary form with a brief, favorable reference to the Copernican theory. On the basis of this reference, some have considered him the first in England to adopt the Copernican system. Probably because this is an elementary text, Recorde cautioned students against rejecting the theory until they are more advanced in the study of astronomy. Still, he implied that the new theory could save the phenomena as well as the older system. The *Castle* is based on **Ptolemy**, **Proclus**, **John of Holywood**, and **Oronce Finé**, but Recorde examined the standard authorities, correcting their textual errors. There are also a number of other works that are no longer extant but that he referred to in the *Castle*. Among these is *The Treasure of Knowledge* (1556), probably on the higher part of astronomy.

Recorde is important primarily as an educational theorist. He insisted on a definite order in the study of the various branches of mathematics. He emphasized simple explanation of fundamental ideas, deferring demonstration to a later stage. Recorde used the dialog form along with visual aids and applications to practical problems. From a historiographical point of view, he is also important for his critical use of authorities and sources. When one considers the Renaissance reverence for ancient authorities, Recorde's caution is exemplary. He is in this regard representative of the more cautious acceptance of **Aristotle** that one finds, especially among English authors in the 16th century. After praising Ptolemy for his diligence, Recorde continues:

> yet muste you and all men take heed, that both in him and in al mennes workes, you be not abused by their autoritye, but evermore attend to their reasons, and examine them well, ever regarding more what is saide, and how it is proved, then who saieth it: for autoritie often times deceaveth many menne."

It seens as if several generations of English students were introduced to mathematics by his writings, thus his reputation as the founder of the English school of mathematical writers.

André Goddu

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Rede, William

Born **England, *circa* 1320**
Died **England, *circa* 1385**

William Rede's chief astronomical work was a recomputation of the Alfonsine Tables for the Oxford meridian, epoch 1340. These Oxford tables enjoyed wide circulation during the 14th and 15th centuries. He also lectured on the *theoria planetarum* and calculated horoscopes for his Merton colleague John Ashenden.

Rede was raised from childhood by Nicholas of Sandwich, a wealthy landholder in the south of England. Rede came up to Oxford in the mid-1330s; he was a fellow of Merton College between 1344 and 1357, where he was a protégé of the astronomer **Simon Bredon**. From the late 1350s onward, Rede held a number of church offices, and was elected Bishop of Chichester in 1368. A significant benefactor of Merton College, he gave it over 100 books, a collection of mathematical instruments, and funds for construction of the Mob Quad library.

Keith Snedegar

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Redman, Roderick Oliver

Born **Rodborough near Stroud, Gloucestershire, England, 17 July 1905**
Died **Cambridge, England, 6 March 1975**

Roderick Redman designed and built a variety of astronomical instruments, applied them to problems in solar and stellar spectroscopy, and revitalized optical astronomy at Cambridge University after World War II. He was the only son and the eldest of four children of Roderick George and Elizabeth Miriam (*née* Stone) Redman. His father, who ran an outfitter's shop inherited from his own father, had left school at age 11, but felt strongly that his son, at least, should receive a full education. Redman senior was an active member, choirmaster, and organist of the Stroud Baptist Church, and Redman junior acquired a lifelong interest in music, being himself a fine organist.

Educated at Marling School, Stroud, Redman won an Open Exhibition in mathematics and physics to Saint John's College, Cambridge, and began his studies there in 1923 at the age of 18. He took the mathematical *tripos* with distinction in 1926, gaining a number of valuable studentships including the Isaac Newton Studentship. He was taken on as a research student by Sir **Arthur Eddington** to work on a theoretical problem in dynamical astronomy, obtaining his Ph.D. in 1930.

Following a traveling studentship at the Dominion Astrophysical Observatory in Victoria, British Columbia, Canada, Redman was appointed assistant director of the Solar Physics Observatory, Cambridge, under **Frederick Stratton** in 1931. Redman remained in Cambridge until 1939, occupied mainly with solar spectroscopy and spectrophotometry. He then moved to South Africa, as chief assistant at the Radcliffe Observatory, Pretoria. Unfortunately, with the outbreak of World War II, the observatory's 74-in. telescope under construction in England, which he had hoped to use, was left incomplete. Redman, however, made the best of what was available to him – the finder on the new telescope's mounting – to perform a valuable photometric program in collaboration with the Royal Observatory at the Cape.

In 1946 Redman was elected a fellow of the Royal Society, and in 1947 was invited to return to Cambridge University as professor of astrophysics and director of the combined University Observatory and Solar Physics Observatory. These two institutions, though on the same site, had different histories; they were now merged to form the Cambridge Observatories. Redman thus inheriting the posts of both Eddington and Stratton.

Redman's first task was a radical modernization. Old instruments were replaced by two new telescopes – a 16-in. Schmidt camera and a 36-in. reflector – and a new solar outfit with a Babcock grating spectrograph. Under Redman's directorship, Cambridge University was transformed into a leading center for astrophysical research, and he himself, a perfectionist in everything he touched, became a highly valued adviser on various national and international bodies. His own fields of activity included successful observations of four total solar eclipses in the course of his scientific life, the last being those of 1952 in Khartoum, where under ideal weather conditions he obtained exceptionally fine high-resolution spectra of the chromosphere, and of 1954 in Sweden.

Among the instruments Redman designed and built were a solar monochrometer, a slit spectrograph that could take a rapid series of coronal images during solar eclipse, a Fabry photometer (at Radcliffe), and, before leaving Cambridge for Pretoria, the spectrograph for the 74-in reflector. In the postwar period, he contributed to the design and construction of a photon-counting photometer and an assortment of narrow-band spectrometers used by his students, who included a large fraction of those who passed through the Cambridge Observatories during his directorship. His research results with these included the demonstration that the residual flux at the centers of strong solar absorption lines was much less than had previously been thought; several determinations of the temperature of the chromosphere; and a database of velocities for single and binary stars later useful as velocity standards and for studies of galactic dynamics.

An early campaigner for British telescopes at better sites than Cambridge, Redman participated in the site testing that led to the location of the Anglo–Australian Observatory and served as a consultant to the Anglo–Australian Telescope Board. He served the Royal Astronomical Society in every capacity except treasurer, and including president (1959–1961). He was president of several commissions and working groups of the International Astronomical Union, was a member of the council of the Royal Society (1953–1954), and held a variety of positions of responsibility in his college (Saint John's) and the astronomical community. He was director of the observatories and, very briefly, of the integrated Institute of Astronomy until his retirement in 1972.

Redman was survived by his Canadian wife, Kathleen, (*née* Bancroft), whom he married in 1935, and their four children.

Marry T. Brück

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Regener, Erich Rudolph Alexander

Born **Schleussenau near Posen (Poznań, Poland), 12 November 1881**
Died **Stuttgart, (Germany), 27 February 1955**

Physicist Erich Regener conducted research on cosmic rays and was the first to outfit a V-2 rocket for taking measurements in the upper stratosphere. Regener, son of a Royal land surveyor, attended Gymnasia in Bromberg, Marienburg (West Prussia), Stargard (Pommern), and yet again in Bromberg, and concluded his school years by sitting for his *Abitur* (final exam) in 1900. He then studied chemistry and physics at the Friedrich Wilhelm University in Berlin. Working under the supervision of Emil Warburg, he was awarded a Ph.D. in 1905 for a dissertation on the influence of ultraviolet radiation on the oxygen–ozone equilibrium. Regener was twice married, first to Victoria Mintschin and then to Gertrud Heiter. He had two children by his first wife.

From 1906 to 1913, Regener worked as an assistant at the Military Technical Academy in Berlin-Charlottenburg. In 1909, he qualified as a lecturer at the University of Berlin by completing a *Habilitationsschrift* (thesis) in nuclear physics, using α particles to determine the elementary electric charge, a subject that Heinrich Rubens had encouraged him to pursue. In 1912, he was appointed honorary professor and, in 1914, succeeded Richard Börnstein as full professor of physics and meteorology and head of the Physics Institute at the Agriculture College in Berlin. Concurrently, Regener taught physics at the Berlin Veterinarian College. From 1915 to 1918, he worked in the battlefields, first as an X-ray field-technician, and after 1917, as an assistant to Fritz Haber, where he was conducting research on gas warfare at the Kaiser Wilhelm Institute. In 1920, Regener became full professor of physics and director of the Physical Institute at the Technische Hochschule in Stuttgart, where he remained active until 1937 and, after the war, from 1945 until his retirement in 1951.

In 1937, Regener was removed from his civil service position because his first wife, Victoria, was a Russian-born Jew. She and his two children were forced to emigrate; the couple was later reunited. (After Victoria's death in 1949, Regener remarried.)

To continue his work, Regener obtained support from the Kaiser Wilhelm Gesellschaft and established the organization's research facility for studies of the stratosphere at Friedrichshafen, on the shores of Lake Constance. Here, he successfully led the institute during the war years by obtaining contracts and money from the National Ministry of Aviation and the German Research Institute for Aviation. After the war, Regener's facility became associated with the new Max Planck Gesellschaft and in 1952 became known as the Max Planck Institute for the Physics of the Stratosphere. The institute was moved to Lindau after Regener's death and was one of the two founding organizations underlying the contemporary Max Planck Institute for Aeronomy.

Regener continued experimental practices that his teacher, Rubens, had been using. His *Habilitationsschrift* led him to undertake research on radioactive compounds and to devise ways of making the trajectories of such radiation visible. Regener's interest in radiation was expanded in the 1920s to involve cosmic radiation. The significance of cosmic rays for astronomy was already apparent, although its corpuscular nature was not yet established. Regener studied the absorptivity of this radiation and performed measurements both at great depths underwater (in Lakes Constance and Alpsee), and at great heights in the atmosphere (up to 30 km). He developed ballooning techniques and automatic meteorological equipment by which it became possible to study other characteristics of the upper atmosphere (composition, moisture, temperature), which were of interest to the emerging aviation industry. With measurements of the ozone concentration in the stratosphere, Regener returned to one of the themes in his dissertation.

Regener endeavored to have his automatic meteorological equipment reach ever-greater heights. He explicitly stressed the advantage and superiority of unmanned meteorological balloons over more expensive manned balloons. In making this argument, he anticipated the contemporary discussion between supporters and opponents of manned space flights. Plans for launching measurement equipment from a balloon located 30 km above the ground were laboratory-tested in 1938, but never successfully realized.

In 1942, Regener and his colleagues Erwin Wilhelm Schopper and Hans Karl Paetzold were given the assignment of developing a scientific application for the V-2 rockets being constructed at the military research facility in Peenemünde, a village on the Baltic coast. In January 1945, instruments were installed in the nose of a rocket (the Regener container), but it was never launched. Portions of the instruments, however, were subsequently taken to the United States, where the first high-altitude research rockets were flown in 1946 from White Sands, New Mexico. In the final years of his life, Regener planned to send measurement equipment into the upper atmosphere using the French Véronique rocket, but he did not live to see the launch.

Bernd Wöbke

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Régis, Pierre-Sylvain

Born **La Salvetat de Blanquefort, (Lot-et-Garonne), France, 1632**
Died **Paris, France, 1707**

Pierre Régis was a proponent of Cartesian philosophy and astronomy. Educated at the Jesuit College at Cahors, and at the University of Paris in theology, he taught at Toulouse and Montpellier, until he succeeded **Jacques Rohault** in Paris in 1680. He was admitted to the newly reformed Académie royale des sciences in 1699.

Régis was a student and follower of Rohault, a very popular lecturer, and one of the principal defenders of an experimentally grounded version of **René Descartes**'s natural philosophy. Régis's *System of Philosophy* of 1690, while based broadly on Descartes, is an eclectic mix of Descartes, **Pierre Gassendi**, and Rohault's probabilistic version of Cartesianism; after Rohault's 1671 *Treatise* it was the most important systematic popularization of Cartesian natural philosophy. The second and third books of Part II of the *System* are devoted to cosmogony and astronomy, and take as their starting point Descartes's theory of vortices.

Régis's one contribution to Cartesian cosmology is in the area of terrestrial gravity, which was a key element in the defense of vortex theory. Descartes had accounted for weight in terms of the complex dynamics of fluid matter around the Earth, which had the effect of pushing bodies toward the center. The theory had been further developed by **Christiaan Huygens** and Rohault. Régis questioned whether Rohault's account of the circulation of fluid matter would actually explain the pushing of bodies toward the center, arguing that it would instead push the body toward some point on the axis between the center of the Earth and the center of the parallel on which the bodies were situated.

Stephen Gaukroger

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Regiomontanus

➔ **Müller, Johann**

Regius, Hendrick

Born **Utrecht, The Netherlands, 29 July 1598**
Died **Utrecht, The Netherlands, 19 February 1679**

Henricus Regius was one of **René Descartes'** first disciples, and one of the principal representatives of Cartesianism in the Netherlands, but his polemical style and intransigent approach soon brought him into conflict with the authorities. He studied in Franeker, Groningen, Leiden, Paris, Montpellier, Valence, and Padua. He taught medicine at the University of Utrecht from 1638.

Descartes showed Regius the material he had intended to publish as *The World*, and Regius had probably based his lectures on this material. In 1646, Regius published his *Fundamenta physices*, which offered a form of Cartesian natural philosophy stripped of the metaphysical foundations that Descartes had provided to legitimate his approach in his *Principles of Philosophy* (1644). Descartes had provided a detailed physical defense of a cosmological system in which the cosmos was indefinitely extended, and comprised an indefinite number of Solar Systems, each with its own planetary system. Although Regius' principal concern was with physiology, he did offer a complete system, so included Cartesian cosmology in Part II of the *Fundamenta*. Even though his account of cosmology here hardly strays at all from that of Descartes, he presented the system as a whole in a way that Descartes considered incautious and superficial, opening up Cartesianism to objections that Descartes' own carefully presented formulations had been designed to avoid. However, in his public dispute with Regius, Descartes was forced to clarify a number of elements of his natural philosophy, although none of these bore directly on cosmological issues.

Stephen Gaukroger

Alternate names

Henricus Regius
Roy, Hendrick de

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Mouy, Paul (1934). *Le développement de la physique cartésienne, 1646–1712*. Paris: Vrin. (Reprint. New York: Arno Press, 1981.)

Regnerus

Frisius, Gemma Reinerus

Reichenau, Hermann von

Hermann the Lame

Reinhold, Erasmus

Born **Saalfeld, (Thuringia, Germany), 22 October 1511**
Died **Saalfeld, (Thuringia, Germany), 19 February 1553**

Erasmus Reinhold is best known for his preparation of the Prutenic Tables, calculated from **Nicolaus Copernicus**'s heliocentric theory.

Reinhold's father Johann (1479–1558) studied in Leipzig and Cologne. He served in the Chancellory of George, Duke of Saxony, and as secretary to the Abbot of the Benedictine monastery at Saalfeld, and held various civic offices in Saalfeld, including that of Mayor. Johann Reinhold prospered sufficiently to enable his son to go from the *Stadtschule* (municipal school) in Saalfeld to Wittenberg University, where he dedicated himself primarily to the study of mathematics under Jacob Milichius. After graduation, Erasmus Reinhold was made professor of higher mathematics (*i. e.*, astronomy). He was elected dean of the philosophical faculty on repeated occasions and, in 1549–1550, rector of the university. Reinhold enjoyed a certain advancement through his close relationship to Philipp Melanchthon.

The most significant of Reinhold's publications were his commentary on the planetary theory of **Georg Peurbach** (1542, and subsequent editions); a textbook for the more advanced study of astronomy that he certainly based on his own lectures; a small work, *De Horizonte*, that appeared as supplement in a number of impressions of **John of Holywood**'s *Libellus de sphaera* (as printed in Wittenberg); and above all the *Tabulae Prutenicae* (Prutenic Tables). Reinhold was the most influential astronomer in Protestant Germany.

Through his fellow professor **Rheticus** Reinhold in Wittenberg had a very early opportunity to acquaint himself with the heliocentric system of Copernicus. Immediately upon its appearance, Reinhold worked his way attentively through Copernicus's *De revolutionibus orbium coelestium*. Following a partial recalculation of observational data (where Copernicus had made several mistakes) and on the basis of Copernicus's improved elements for planetary orbits, the constant of precession, the length of the year, and the obliquity of the ecliptic, as well as his own theory of lunar motion and approach to triangulation (among other factors), Reinhold produced new planetary tables. After many years of work, they appeared first in Tübingen in 1551, commissioned by Melanchthon and Duke Albert of Prussia, and named *Tabulae Prutenicae* in honor of the latter.

Reinhold did not endorse the heliocentric system, but recognized that the mathematical theory of this system represented a significant advance in relation to new observational data. He made no statement on the question of the physical reality of the heliocentric system; as a strongly "classically" minded astronomer, adhering to the conceptual model of a division between physics and astronomy, he did not accept that such a theory raised any problem. For Reinhold the question was irrelevant as he subscribed to the traditional scientific concept of astronomy "saving the appearances."

The Prutenic Tables rendered the heliocentric system operable for practical astronomy, in particular for the calculation of calendars and horoscopes. From the 1570s, Reinhold's tables were one of the most important astronomical tables, and they were instrumental in Copernicus being generally recognized, from the end of the 16th century, as one of the most important astronomers. The accuracy of the planetary positions as calculated proved, with time, to be a significant factor in the acceptance of the totality of the heliocentric system, rather than just its mathematical parameters. (Subsequently, larger errors became evident once again, as **Johannes Kepler** and others showed.) The tables were significant for the furtherance of the heliocentric world-system, even though Reinhold himself always recognized the geocentric.

Reinhold's brother Johannes became professor of mathematics in Greifswald in 1549, but died in 1552. Reinhold's son, Erasmus Jr. (1538–1592) studied mathematics and medicine in Wittenberg under the care of Melanchthon, and then in Jena, and became doctor of medicine and municipal doctor in Amberg and Saalfeld. Later he became *Bergvogt* (mountain steward) to the Elector of Saxony, and wrote works on land surveying as well as calendars, which appeared regularly for many years in Erfurt.

Jürgen Hamel
Translated by: *Peter Nockolds*

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——— *Commentarius in opus revolutionum Copernici*. MS lat. fol. 391. Staatsbibliothek Berlin, Preussischer Kulturbesitz.

Reinmuth, Karl Wilhelm

Born **Heidelberg, (Germany), 4 April 1892**
Died **Heidelberg, (Germany), 6 May 1979**

Before the advent of automated search techniques, Karl Reinmuth became the world's most successful asteroid hunter. He discovered a total of 389 minor planets, including some of the first known to exist outside of the main asteroid belt.

A lifelong resident of Heidelberg, Reinmuth studied at the Ruprich-Karls University. His doctoral thesis (1916), entitled "Photographische Positionsbestimmung von 356 Schultzschen Nebelflecken," reported on the position determinations of 356 nebulae, originally cataloged in 1875 by Herman Schultz of Uppsala.

Reinmuth joined the staff of the Königstuhl Observatory near Heidelberg as a volunteer in 1912, working under the supervision of director **Maximillian Wolf**, the first astronomer to apply photographic techniques to the discovery of asteroids. Reinmuth located his first new minor planet, (796) Sarita, on 15 October 1914. Upon Wolf's death, Reinmuth was appointed director of the Königstuhl Observatory in 1932 and served in that capacity until his retirement in 1957.

After World War I, Reinmuth was given responsibility for resuming a sky survey begun by Adam Massinger, another of Wolf's assistants. Massinger had been urged to compile a photographic record of more than 4,000 objects included in **John Herschel**'s *A General Catalogue of Nebulae and Clusters of Stars* (1864). Photographic plates from the Heidelberg Observatory, some dating back to 1900, were used in this collection. The project was halted by the outbreak of war; Massinger was killed in battle at Ypres. Reinmuth continued working on the project until it was completed in 1924.

In 1926, Reinmuth published the catalog entitled *Die Herschel-Nebel nach Aufnahmen der Königstuhl-Sternwarte*. Despite its German-language title, the volume listed the approximate dimensions, position angles (where relevant), and partial descriptions in English of the objects (chiefly galaxies) originally given by Herschel. At that time, Reinmuth's catalog was the only such listing that contained position angles of galaxies in the northern heavens.

Between 1919 and 1937, Reinmuth discovered all of the Trojan asteroids (seven) recognized during that period. Trojan asteroids have nearly circular orbits and are located at the leading or trailing Lagrangian points (L4 and L5) of Jupiter's orbit. During a routine asteroid patrol, Reinmuth discovered a faint comet on 22 February 1928 now known as 30P/Reinmuth.

During the 1930s, a competition of sorts developed between Reinmuth and **Eugène Delporte**, of the Belgian National Observatory at Uccle, in the discovery of Earth-approaching asteroids. Following Delporte's detection of minor planet (1221) Amor in 1932, Reinmuth recorded the trail of a nearby, rapidly moving asteroid whose orbit was found to cross that of the Earth. It was given the name (1862) Apollo, after the Greek Sun god. Reinmuth's discovery proved to be the first object in a class of asteroids sharing similar orbital properties. Apollos are one of three classes of Earth-approaching asteroids, along with the Amors and Atens, whose perihelion distances lie inside the orbit of Mars. Apollo-type asteroids have semimajor axes (a) that are greater than or equal to 1 AU and perihelion distances (q) that are less than or equal to 1.017 AU. Reinmuth discovered another member of the Apollo class of minor planets, (69230) Hermes, which remained "lost" by astronomers until its accidental rediscovery in 2003. For over 50 years, Hermes held the close-approach record of only 800,000 km from Earth.

In 1980, evidence was presented by physicist **Luis Alvarez** and colleagues that an asteroid's collision with the Earth was responsible for the Cretaceous–Tertiary extinction of the dinosaurs. Consequently, the potential danger of near-earth asteroids [NEAs] has been taken far more seriously by astronomers than in Reinmuth's day. Automated search techniques enable the discovery of NEAs to be made at a remarkable pace – a feat that surely would be the envy of Reinmuth.

Reinmuth is commemorated with the naming of minor planet (1111) Reinmuthia.

Robert D. McGown

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Renieri, Vincenzio

Born **Genoa, (Italy), 30 March 1606**
Died **Pisa, (Italy), 5 November 1647**

A friend and disciple of **Galileo Galilei**, Vincenzio Renieri is best remembered for his work on the satellites of Jupiter. Although little is known about his early life, Renieri joined the Olivetan Order in 1623, which initially took him to Rome and a decade later to Siena, where he met Galilei (1633). Thereafter, Renieri made frequent visits to Arcetri and soon became an intimate friend of Galilei. Working closely with Vincenzio Viviani, Renieri was given the task of continuing Galilei's observations of the satellites of Jupiter and improving the computational tables. To that end, Galilei entrusted Renieri with all of his papers dealing with Jupiter's satellites, which were to be perfected and sent to the States-General of Holland as the basis for determining longitude at sea. Having accepted the chair in mathematics at Pisa (previously held by Dino Peri and earlier still by Galilei), Renieri continued to supplement Galilei's observations while improving his methods.

Unfortunately, Renieri published only one work, the *Tabulae mediceae secundorum mobilium universales* (Florence, 1639). Although the title is tantalizing, Renieri's widely discussed tables for Jupiter's satellites were not published during his lifetime. **Jean-Baptiste Delambre**, among others, garbled the story about Renieri's sole publication, the *Tabulae mediceae*, not only indicating it was published before his fourth birthday but also questioning whether Renieri's satellite observations ever existed. The *Medicean Tables* say nothing about the Medicean satellites; instead, they represent a typical effort to improve **Johannes Kepler**'s *Rudolphine Tables* for the planets. Deploring the gross errors in earlier ephemerides (Ptolemaic, Alphonsine, Prutenic), Renieri claimed a simpler method for calculating longitudes by means of a two-step procedure, which he applied first to the superior planets, then to the inferior. His treatment of planetary latitudes is similar but more complicated. Renieri concluded by comparing his results (for the middle terrestrial latitudes), arguing that his tables were superior to the Rudolphine, Tychonic, Danish, and Landsbergian.

In the end, Renieri's observations of Jupiter's satellites were not printed until the mid-19th century. Although the Grand Duke of Tuscany ordered the ephemerides published (later echoed by his brother, Prince Leopold), Renieri died prematurely, and his manuscript was lost. (A questionable report suggests it was stolen by one Giuseppe Agostini.) The loss was unfortunate, as the synodic periods Renieri supplied were remarkably accurate, clearly superior to values given by **Simon Mayr** and other contemporaries. **Alexandre Pingré** indicates Renieri had an excellent telescope but made many observations with a mediocre quadrant. Several of Renieri's observations are cited in **Giovanni Riccioli**'s *Almagestum novum* (pt. I) .

Robert Alan Hatch

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Respighi, Lorenzo

Born **Cortemaggiore, (Emilia-Romagna, Italy), 7 October 1824**
Died **Rome, Italy, 10 December 1889**

Alongside **Angelo Secchi** and **Giovanni Schiaparelli**, Lorenzo Respighi can be considered the most important Italian astronomer of the second half of the 19th century. He was a pioneer in solar spectroscopy.

Respighi completed his early studies in Parma and his higher studies at the University of Bologna, where he obtained his degree *ad honorem* in philosophy and mathematics in 1847. At age 18, he was inducted into the Accademia delle Scienze of Bologna, and four years later he became a permanent member of the Accademia Benedettina. In 1849, Respighi was appointed as substitute to the chair of mechanics and hydraulics at Bologna. In 1851, he was appointed professor of optics and astronomy, a chair vacant for 3 years, and in 1855 he was also named director of the Astronomical Observatory. Respighi held these positions until 1864, when he was dismissed for refusing to take an oath of loyalty to the government of the Kingdom of Italy, which succeeded the papal government in Bologna.

Respighi moved to Rome in 1865, and in August of that year Pope Pius IX appointed him professor of optics and astronomy at the University of Rome La Sapienza and director of the Roman Observatory at the Capitol, a post he held until his death.

Respighi's scientific work began with a mathematical opus entitled *Principi del calcolo differenziale*, which **Augustin Cauchy** presented at the Académie des sciences in Paris. He subsequently became interested in positional astronomy, geodetic astronomy, and instrumental astronomy, but his main focus was physical astronomy (spectroscopy) and he is considered one of the pioneers in this field of study in Italy. In positional astronomy, Respighi compiled three catalogs, published between 1877 and 1884, of the mean declinations of over 2,500 stars at the 1875.0 epoch. Each star was observed several times using Ertel's meridian circle at the Bologna Observatory, both directly and applying the new method for observing zenithal stars by reflection in a basin of mercury. During these observations, he did extensive research into the aberration of light, conducting experiments using a water-filled telescope. He also conducted experiments on the variation of the speed of light in a vacuum, again with Ertel's meridian circle, using a thick piece of glass made specifically for this purpose with numerous air bubbles inside. Respighi also observed planets and comets, discovering three comets (C/1862 W1, C/1863 G2, and C/1861 Y1). In geodetic astronomy, Respighi determined the latitude of the Bologna Observatory and the absolute declination value for the city, as well as the latitude of the Capitol Observatory and of the prime meridian of Monte Mario in Rome. He also studied meteorology, writing several dissertations on the climate of Bologna, in which he reduced and discussed the meteorological and magnetic data accumulated by the Bologna Observatory in 45 years of observations (1814–1859).

Respighi's most important astrophysical researches involved stellar scintillation and the study of solar physics. Between 1869 and 1885, he conducted systematic observations of the border of the Sun, using the method invented by **William Huggins** in 1869. Known as "the widened slit method," it entailed placing the slit of the spectroscope tangential to the border of the Sun, widening the slit to include the entire height of the solar prominences, and placing a piece of red glass in front of the eyepiece. Respighi also studied the relationship between sunspots and solar prominences, deducing that at the points of the border of the Sun where a sunspot occurs or disappears, the chromosphere looks thinner. In 1870, he participated in the Italian expedition to observe the solar eclipse in Sicily, and in 1873 he began a series of measurements of the diameter of the Sun to study its variations in relation to the sunspot cycle. Lastly, Respighi noticed that the spectral lines over the sunspots look widened and deformed, a phenomenon that was later studied by

George Hale and is due to the Zeeman effect. He also studied the spectrum of the aurora borealis and compared this spectrum to the one of zodiacal light.

When head of the Capitol Observatory, Respighi engaged in a long dispute with Secchi about who had invented the use of the objective prism to study the stellar spectra and the nature of sunspots. He discovered that on the instrument invented by **Joseph von Fraunhofer** in 1815, the angle of refraction was too large, so it could not be used for spectra. Thus, Respighi had a prism made with an angle of refraction of just 12° and mounted it on the equatorial telescope at the Capitol. With this instrument, on 15 February 1869, he was able to show French physicist **Marie Cornu** the excellent stellar spectra he had obtained. The instrument used by Respighi spread rapidly and became one of the chief aids in astrophysics. With Secchi, **Pietro Tacchini**, **Giuseppe Lorenzoni**, and A. Nobile, in 1871 Respighi helped establish the Italian Society of Spectroscopists, although he rarely participated actively due to his disagreement with Secchi.

Respighi was a member of the European Commission for the Degree and of the Royal Superior Commission of Weights and Measures. Likewise, he was a member of numerous academies, such as the Accademia delle Scienze of Bologna, the Accademia dei Lincei, the Italian Society of Science known as the Società dei XL, the Geneva Society of Physics and Natural History, and the Royal Society of London. He was conferred with the Order of Saints Mauritius and Lazarus, the Order of the Crown of Italy, and the Military Order of the Portuguese Crown.

Respighi's manuscripts are in the Historical Archives of the Department of Astronomy of the Bologna University and in the Historical Archives of the Rome Astronomical Observatory in Monte Porzio.

Fabrizio Bònoli

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Rheita, Antonius Maria Schyrleus de Schyrle [Schierl, Schürle] Johann Burchard

Born **Reutte, Tyrol, (Austria), 1604**
Died **Ravenna, (Italy), 1659 or 1660**

Antonius de Rheita was a telescope maker, observer, and supporter of the Tychonic system. He described the bands of Jupiter and developed the compound eyepiece.

Rheita was born in a noble family; "de Rheita" was derived from his birthplace. Rheita was educated in the Augustinian abbey of Indersdorf, Bavaria. On 14 October 1623, he enrolled at the University of Ingolstadt, where optics and astronomy were taught in the tradition of **Christoph Scheiner** and **Johann Cysat**. Three years later, Rheita left without a degree to become a Capuchin monk in the monastery of Passau, taking the name Antonius Maria. In 1636, he left Passau to become reader in philosophy at the Capuchin monastery of Linz. There, he met Philipp Cristoph von Sötern, the elector of Trier, for whom he worked for several years. In 1642, Rheita was in the Capuchin monastery of Cologne, where he conducted astronomical research and constructed telescopes that would result in his first publication, *Novem stellae circa Jovem visae, circa Saturnum sex, circa Martem nonnulla* (Nine stars seen [or observed] around Jupiter, six around Saturn, several around Mars), in 1643. That year, he met the instrument and telescope maker Johann Wiesel in Augsburg, where Rheita presumably was to give support to the nearby Bridgettine monastery in Altomünster of his brother Elias. One year later, Rheita was in Antwerp to prepare the publication of his main work *Oculus Enoch et Eliae*, before returning, in 1645, to Trier, again in the service of Sötern until the latter's death in 1652.

In those years, Rheita ran a workshop that produced telescopes for, among others, the Archbishop-Elector of Mainz. In Belgium to prepare a new edition of his *Oculus Enoch et Eliae* in 1653, he was informed of accusations against him by the Inquisition. Imprisoned in Bologna and later in Ravenna, Rheita's plans to build an observatory in Mainz would never materialize. On 27 November 1659 or 14 November 1660 (depending on the source used) he died, in unclear circumstances, in confinement.

In his *Oculus Enoch et Eliae*, Rheita defended the Tychonic world system, criticizing the Copernican system as established by **Philip Lansbergen**. In this he followed Scheiner and Cysat, and his friend and supporter Eryceus Puteanus. Defending the physical reality of the geoheliocentric world system was part of Rheita's contribution to the Counter-Reformation.

Rheita also published a map of the Moon in his *Oculus Enoch et Eliae*. With the exception of **Francesco Fontana**'s unpublished lunar drawings of 1629 and 1630, this was the first map to present the Moon south up, as seen through a telescope consisting of two convex lenses. However, Rheita's map was uninfluential.

Rheita's main contribution to astronomy was in the field of telescope design. In his 1643 work *Novem stellae circa Iovem, circa Saturnum sex, circa Martem nonnullae* Rheita claimed to have discovered a number of new satellites of the superior planets. In particular, on 29 December 1642, he said he discovered five satellites of Jupiter, above the four satellites already discovered by **Galileo Galilei** in 1610. The letter spread very rapidly to Paris**. Pierre Gassendi** published his answer together with Rheita's letter in April 1643. Gassendi correctly claimed that the new satellites were fixed stars. Rheita argued that those satellites could only be revealed by his recently invented binocular telescope. *Oculus Enoch et Eliae* referred to the binocular telescope, with Henoch and Elias each symbolizing one eye. With the same instrument, Rheita observed the bands on Jupiter, as he announced in a letter of 18 June 1651 to the Elector of Mainz.

More important for telescope design was the compound eyepiece, developed in collaboration with Wiesel around 1644. In 1611, **Johannes Kepler** had already introduced a third convex lens, that is, an erector lens, to reinvert the image seen through his telescope; it consisted of two convex lenses. Rheita's telescope consisted of four convex lenses, one objective lens and three ocular lenses. (Rheita introduced a field lens beside an erector lens.) The focal point of the objective lens coincided with the focal point of the third ocular lens. The introduction of the third ocular lens allowed overcoming the main problem of the telescopes of the first half of the 17th century: the limitation placed on magnifications by the progressive restriction of the field of view. Moreover, Rheita discovered that the angle of view was a function of the diameter of the ocular lenses. As a consequence, the ocular lenses were often made larger than the objective lens, resulting in an inversion of the trumpet shape of the tube with respect to earlier telescopes. The compound eyepiece also limited chromatic aberration.

Rheita's design of telescopes became known throughout Europe, mostly through telescopes produced by Wiesel in Augsburg. The same design was soon used in England by Richard Reeve (of Hartlib's circle), in Holland by **Christiaan Huygens**, in Italy by **Giuseppi Campani,** and in France by another Capuchin monk, Chérubin d'Orléans. Rheita in his book suggested that polishing on paper glued into a spherical mould would allow for precise polishing of spherical lenses of long focal lengths. This new polishing technique, together with the compound eyepiece, allowed for longer and longer telescopes, and the astronomical discoveries that went along with it, during the second half of the 17th century.

Sven Dupré

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Rheticus

Born **Feldkirch,Vorarlberg, (Austria), 16 February 1514**
Died **Kassa (Košice, Slovakia), 4 December 1574**

Georg Rheticus was among the first to adopt and spread the heliocentric theory of **Nicolaus Copernicus**.

Georg von Lauchen, later known as Rheticus, was born in an Austrian town near the Swiss border. His father, Georg Iserin, was the town doctor and a government official; he taught his son until 1528, when he was tried on a charge of sorcery, convicted, and beheaded. One of the consequences of this execution was that his name could no longer be used; therefore, Georg's mother, an Italian noblewoman named Tommasina de Porris, reverted to her maiden name. Since "de Porris" means "of leeks" in Italian, Rheticus preferred to translate it into German "von Lauchen." Later, he took the additional name of Rheticus, after the ancient Roman province of Rhaetia in which he had been born.

Rheticus studied first at the Latin school in Feldkirch, then at the Frauenmünsterschule in Zürich until 1531. In 1533 he matriculated from the University of Wittenberg, where he received the title of *magister artium* in 1536. Soon afterward, thanks to Philipp Melanchthon's support, Rheticus was appointed to teach arithmetic, geometry, and astronomy at the University of Wittenberg.

In October 1538, Rheticus went on leave to visit leading astronomers and mathematicians: **Johannes Schöner** in Nüremberg, **Peter Apian** in Ingolstadt, Joachim Camerarius in Tübingen, and Copernicus in Frombork (Frauenburg). In September 1541, Rheticus went back to Wittenberg, where he was elected dean of the arts faculty. A few months later he was offered a post as professor of higher mathematics at the University of Leipzig, where he began teaching in October 1542.

In 1545, Rheticus left Leipzig to study abroad. After making a short stay in Feldkirch, he spent some time in Italy. Toward the end of 1546, he suffered a severe mental disorder in Lindau, a town on Lake Constance; this aroused some unfounded rumors about his death. But his health recovered to allow Rheticus to teach mathematics and astronomy at Constance for 3 months in late 1547. Then he studied medicine in Zürich with Konrad von Gesner.

In February 1548, Rheticus went back to Leipzig, where, with Melanchthon's influence, he was made a member of the theological faculty. In this period he was deeply engrossed in his university duties and sent many books to the press, among them a Latin translation of Euclid's *Elements* (1549), a calendar and ephemeris (1550), and the *Canon doctrinae triangulorum* (1551), which was the first publication to contain all the six trigonometrical functions. In April 1551, Rheticus was accused of having a homosexual affair with one of his students, and the consequent scandal compelled him to escape from Leipzig. His friends, such as Melanchthon, stopped supporting him, and he was tried in his absence by a town court. Rheticus was condemned to 101 years of exile, and all his possessions in Leipzig were impounded.

After leaving Leipzig, Rheticus spent some time at Chemnitz, before establishing himself in Prague. In 1551/1552 he studied medicine at the University of Prague. In 1553 Rheticus made a trip to Vienna, and the following year he moved to Kraków, Poland, where he remained for 20 years as a practicing doctor, though he continued to devote himself to mathematics and astronomy. In this period he worked on the trigonometric tables, projected and constructed astronomical instruments, and carried out astronomical observations and alchemy experiments.

In 1574 Rheticus left Kraków and went to Kassa (Kosice), by request of the local magnate Johannes Ruben. Here he was visited by Valentine Otho, who was at that time a student of mathematics at the University of Wittenberg. Rheticus died shortly afterward. He left an unfinished manuscript, which was then completed by Otho and published with the title of *Opus palatinum de triangulis* (1596); another book, the *Thesaurus mathematicus*, was edited by Bartholomeo Pitiscus (1613). Thanks to these posthumous works, Rheticus can be considered one of the most important authors of trigonometrical tables.

Rheticus was among the first to adopt and spread the heliocentric theory of Copernicus. Rumors of this hypothesis had reached Rheticus at Wittenberg. In May 1539 he traveled to Poland to visit Copernicus, and ended up staying at Frombork for 2 years, during which time he was able to persuade Copernicus to let him study the virtually completed *De revolutionibus*. Rheticus became enthusiastic over the heliocentric theory and tried to convince Copernicus to publish it. Since his efforts were rewarded with no success, Rheticus wrote a brief summary of the theory, which was published in Danzig at the beginning of 1540, explicitly authorized by Copernicus, under the title of *Narratio prima de Libris Revolutionum eruditissimi viri et mathematici excellentissimi, reverendi Domini Doctoris Nicolai Copernici Torunnaei Canonici Varmiensis* (First report on the Books of the Revolutions of the learned gentleman and distinguished mathematician, the Reverend Doctor Nicolaus Copernicus of Torun, Canon of Warmja).

Rheticus's booklet, written in the form of a letter to Schöner, was the first illustrated account of Copernicus's heliocentric theory. The *Narratio prima* is not, however, a pure summary of *De revolutionibus*; it has a different structure. First of all, Rheticus explained the questions about the motion of the fixed stars and the precession of the equinoxes: Curiously, therefore, at the beginning of his booklet he did not speak of the three motions of the Earth, but introduced them at the end. Rheticus's expository method was contrary to that used by Copernicus. While the latter started from the statement that the Earth moves and then tried to demonstrate it by analyzing the apparent motions of the stars, Rheticus expounded these motions of the stars in order to be able to assert that the motions of the Earth are the unique way of explaining them. This expository order was a consequence of the pedagogical aims that Rheticus wanted to achieve, but perhaps there is also another reason: Rheticus seemed to underline that the apparent motions of the stars and those of the Sun, which the astronomical tradition had considered as separated matters, are strictly correlated and can be coherently explained only by assuming a moving Earth. For many decades the *Narratio prima* remained the best popularization of the heliocentric theory. The first edition of 1540 was enthusiastically received, and a second edition was published in Basel less than a year later. The *Narratio* was reprinted as an appendix of Copernicus's *De revolutionibus* in 1566 and of **Johannes Kepler**'s *Mysterium cosmographicum* in 1596.

Probably as a result of the *Narratio's* success, when Rheticus left Frombork in 1541, Copernicus allowed him to take a complete copy of *De revolutionibus* to arrange for its publication. Rheticus entrusted publication of the manuscript to Johann Petrius in Nüremberg, but he could not supervise the entire work and left oversight of the printing to a Lutheran theologian, **Andreas Osiander**, who made some unauthorized additions to the manuscript. When Rheticus received the first copies of the printed book in April 1543, he saw that the title had been changed: Instead of *De revolutionibus*, the printed version read *De revolutionibus orbium coelestium*. The worst change, however, was the insertion of an anonymous preface, which affirmed that the book contained a mere mathematical hypothesis, not a description of the real universe. Rheticus suspected that Osiander had made the changes and probably did not approve; however, he did not take an official position against the preface, since perhaps he considered it a way of making the heliocentric theory more acceptable for ecclesiastics and theologians.

Marco Murara

Alternate name

Lauchen, Georg Joachim von

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Rho, Giacomo

Born **Milan, (Italy), 1593**
Died **Beijing, China, 27 April 1638**

Italian Jesuits Giacomo Rho and **Johann Schall von Bell** were appointed by the emperor in Beijing to reform the Chinese calendar. Rho brought the Tychonic cosmological model to China.

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Ricci, Matteo

Born **Macerata, (Marche, Italy), 6 October 1552**
Died **Beijing, China, 11 May 1610**

Matteo Ricci carried out an astonishingly successful mission to Chinese scholars during which he greatly improved the maps of China and introduced Euclidean geometry and trigonometry there.

Ricci's parents were Giovanni Battista Ricci and Giovanna Angiolelli. Matteo entered the Jesuit order in 1571, and after his courses in rhetoric, philosophy, and theology he studied mathematics at the Roman College under **Christoph Clavius**.

In 1577 Ricci departed Rome to join the Jesuits working in China and arrived there in 1583, where he worked for 27 years. He first opened a residence in Nanking for himself, his fellow Jesuits, and his scientific instruments. (For a time suspicious landlords would drive Ricci and his companions from their dwellings, until they hit on the plan of renting haunted houses; then no one bothered them.) Gradually Ricci was welcomed to the academies and gained many influential friendships. Later he became the court mathematician in Beijing, and there he stayed for the rest of his life.

Jesuits were practically the sole source of Chinese knowledge about western astronomy, geometry, and trigonometry. Appointments in the Astronomical Bureau provided the Jesuits with access to the ruling elite, whose conversion was their main object. Mathematical and astronomical treatises demonstrated high learning and proved that the missionaries were civilized and socially acceptable.

Matteo Ricci brought trigonometry to China, where it had remained in primitive form until the Jesuits came. Ricci's successors, **Ferdinand Verbiest** and **Johann Schall von Bell**, used geometric and trigonometric concepts to bring about a revolution in the sciences of astronomy, the design of astronomical instruments, mapmaking, and the intricate art of making accurate calendars.

The Jesuits were inveterate mapmakers and were continually traveling around the empire of China, even though travel conditions were quite inconvenient. The *Philosophical Transactions of the Royal Society* recounts 52 such journeys by Ricci and Verbiest alone.

Ricci designed and displayed a great world map, which brought about a revolution in traditional Chinese cosmography. For the first time the Chinese had an idea of the distribution of oceans and landmasses. This was the beginning of his major contribution to the diffusion of knowledge through his more than 20 works in Chinese on such topics as mathematics and astronomy.

For 20 years Ricci tried to reach the emperor in person, but the emperor was a recluse not accustomed to seeing even his own people. Then, unexpectedly, the emperor summoned Ricci and his companions to inquire about a ringing clock brought to him by the Jesuits. His own scientists had failed to fix it when it stopped. Since the emperor could not receive these foreigners in person, he had an artist draw full-length portraits of them, so that they could have a vicarious interview.

Another opportunity was occasioned by an eclipse of the Sun: The prediction of the expected time and duration made by the emperor's own Chinese astronomers differed considerably from the Jesuit prediction. When the latter prediction proved correct, the place of the Jesuit mathematicians was secure. It is interesting that the Jesuits taught the Chinese the heliocentric theory, unaware that **Galileo Galilei**'s trial had taken place, and it had been forbidden by Rome to be taught as a proven fact. There was a more than 5-year lag in communications.

Ricci's books *Geometrica Practica* and *Trigonometrica* were translations of Clavius's works into Chinese. In 1584 and 1600 he published the first maps of China ever available to the west. As author, the Chinese geometrical works for which Ricci is remembered were books on the astrolabe, the sphere, measures, and isoperimetrics. But especially important was his Chinese version of the first six books of Euclid's *Elements*, which was written in collaboration with one of his pupils and entitled *A First Textbook of Geometry*.

The prestige Ricci gained in the highest cultural spheres by his wisdom, scientific knowledge, and capacity for philosophical speculation won him a hearing when he spoke of the gospel message. Without any trace of superiority in his manner, he used a process of dialog that was characterized by an esteem and respect for everyone. Ricci's success was due to his personal qualities, his complete adaptation to Chinese customs (choosing the attire of a Chinese scholar), and his authentic knowledge of mathematics, physics, and astronomy. (His works included Chinese texts on religious and moral topics, as well as writings on scientific topics.) It is still possible to visit Ricci's 8-ft.-high tomb in the Beijing suburbs.

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Riccioli, Giovanni Battista

Born **Ferrara, (Italy), 17 April 1598**
Died **Bologna, (Italy), 25 June 1671**

Giovanni Riccioli was a pioneer in lunar astronomy who first named craters and mountains on the Moon for scientists. He also perfected the use of the pendulum for time measurement.

Riccioli entered the Jesuit order in 1614, and studied rhetoric, philosophy, and theology in Parma and Bologna. During this period he began his studies in astronomy.

Riccioli published one of the earliest books on astronomy: *Almagestum Novum* (Bologna, 1651). His chapter concerning the Moon contains two large maps (28 cm in diameter), one of which shows – for the first time – the effects of librations and introduces new lunar nomenclature. Almost all of his names for lunar objects are still in use today. It is the first map to name craters and mountains for scientists and prominent people instead of abstract concepts. A copy of Riccioli's lunar map stands at the entrance to the lunar exhibit at the Smithsonian Institute, and was described in detail in the *Philosophical Transactions* of the Royal Society. It was meticulously drawn by another Jesuit, **Francesco Grimaldi**.

Jesuit astronomers in Rome such as Riccioli had a great advantage over others because they were able to gather information from their former pupils spread out across the globe, in places as disparate as South America, Africa, China, Japan, and India. There were many Jesuit astronomical observatories throughout the world that efficiently gathered data concerning lunar and solar eclipses as well as transits of Venus. By the time of the (temporary) suppression of the Jesuit Society in 1773, no fewer than 30 of the world's 130 astronomical observatories were run by Jesuits. This information enabled Riccioli to compose a table of 2,700 selenographical objects, incomparably more accurate than anything previously known.

Riccioli also made many important measurements in order to refine his existing astronomical data, such as the radius of the Earth and the ratio of water to land on its surface. He compiled star catalogs and described sunspots, the movement of a double star, and the colored bands of Jupiter.

In physics, Riccioli went beyond the preliminary work of **Galileo Galilei** and succeeded in perfecting the pendulum as an instrument to measure time, thereby laying the groundwork for a number of important later applications. Riccioli once persuaded nine of his fellow teachers to count 87,000 oscillations over the course of a day, enabling him to identify an error of three parts in a thousand. In his book *God and Nature*, David Lindberg notes that it was Riccioli, not Galilei, who first accurately determined the rate of acceleration of a falling body. Noting the collaborative efforts of Jesuits, he argues that Jesuit scientists, rather than the Academia del Cimento or the Royal Society, formed the first true scientific society. **Athanasius Kircher**, for example, in his ability to collect observations from a worldwide network of informants was more than a match for **Marin Mersenne** in Paris or Henry Oldenburg in London, and he published this information in massive encyclopedias, which were indispensable in disseminating scientific data and theories.

Riccioli contributed also to geography, publishing tables of latitude and longitude for many different locations. This facilitated later developments in cartography.

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Riccò, Annibale

Born **Modena, (Italy), 15 September 1844**
Died **Rome, Italy, 23 September 1919**

Annibale Riccò carried out an exhaustive study of solar prominences, of which he amassed over 20,000 observations, and deduced the existence of the solar wind.

Riccò was educated at the University of Modena, where he received his bachelor's degree in mathematics (1866) and doctorate in natural sciences (1868). He also earned a degree in civil engineering from the Polytechnic Institute of Milan (1868) and began his career as an architect.

Riccò's involvement with astronomy began as an observatory assistant at Modena. In 1872, he cofounded the Society of Italian Spectroscopists, whose efforts were devoted chiefly toward an improved understanding of the Sun. Temporarily an instructor of physics at Naples, Riccò was subsequently appointed an astronomer at the Royal Observatory in Palermo. In 1885, he founded an observatory at Catania, and in 1890 became director of the Catania Observatory and Mount Etna Observatories and acquired the chairmanship of astrophysics at the University of Catania. Riccò held these posts for the remainder of his life.

Riccò's data revealed the solar prominences to be of two principal types, either quiescent or active. He was among the first to argue that dark "filaments," which appeared superimposed on the solar disk, were themselves prominences. In 1892, Riccò demonstrated that delays of roughly forty to forty-five hours occurred between the crossings of sunspots on the solar meridian and resulting terrestrial magnetic disturbances. Particles emitted by the Sun, and whose existence Riccò inferred, are now recognized as the "solar wind."

Riccò oversaw the Catania Observatory's involvement with the International *Carte du Ciel* Astrographic Chart and Catalogue project, and attempted, albeit unsuccessfully, to photograph the Sun's corona without an eclipse from the top of Mount Etna with American astronomer **George Hale** (1894). Perhaps in relation to his solar studies, Riccò observed numerous bright comets, including C/1908 R1 (Morehouse) and 1P/1909 (Halley). In 1899, he became coeditor, and in 1905, editor, of the *Memoire della Società degli Spettroscopisti Italiani*, founded by **Angelo Secchi** and **Pietro Tacchini**. Riccò traveled abroad to witness several total solar eclipses.

Riccò's solar research netted him some prestigious awards, including the Royal Prize of the Accademia dei Lincei, and a Knight of the Crown of Italy. Riccò was thrice elected an executive officer of the International Union for Cooperation in Solar Research [IUCSR] and, in 1919, a vice president of its successor, the International Astronomical Union [IAU]. Both appointments reflected his strong commitments toward fostering solar research and international scientific cooperation.

Jordan D. Marché, II

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Richard of Wallingford

Born **England, *circa* 1291**
Died **England, *circa* 1335**

Richard of Wallingford is probably best remembered for the astronomical clock he designed for the abbey of Saint Albans. He also wrote books about astronomical instruments and about trigonometry.

Richard was born in either 1291 or 1292 to William, a blacksmith, and Isabella. William died when Richard was 10, whereupon Richard was adopted by William de Kirkeby, Prior of Wallingford. He attended Oxford for 6 years, graduating with an AB degree, then assumed the monastic habit at Saint Albans. He was ordained deacon in 1316 and priest in 1317. His abbot sent him back to Oxford, where he studied for 9 years and received a Bachelor of Divinity degree in 1326.

In the same year the presiding abbot died, and Richard was elected the new abbot of Saint Albans. Despite contracting leprosy at about that time, which led to blindness in one eye and later robbed him of his power of speech, Richard was nonetheless a strong abbot. He brought Saint Albans out of debt, quelled riot among the townspeople, and survived internal struggles that led to a papal inquisition.

Richard's greatest achievement was the clock that he designed and had built for the abbey. It was the first purely mechanical clock of which there is a complete record. It not only struck the hours of the day, but also indicated the positions of the Sun, Moon, and planets, as well as lunar phases and solar eclipses; it may also have had a tidal dial. It was a clock of unprecedented complexity and accuracy for its time and was unsurpassed in quality for the next 200 years. When King Edward III chided him for building a clock instead of more churches, Richard replied that many abbots could build churches, but after he was dead, no one could complete the work of the clock. The clock itself is no longer in existence, a victim of the dissolution of the monasteries in the 16th century.

While studying at Oxford, Richard produced several works of mathematics and astronomy that are also remarkable for their time. The *Quadripartitum* and *de Sectore* comprised the most comprehensive compendium of trigonometry in Europe before the end of the 1400s. This also was the first instance where trigonometry was separated from its applications (*e. g.*, astronomy) and dealt with in an abstract manner. Richard wrote the *Exafrenon*, a treatise on the prediction of weather and natural events that were believed to be governed by planetary influence. He also wrote two manuscripts devoted to astronomical instruments he invented. The *Albion* described his version of an *equatorium* to calculate planetary positions and eclipses. It was a completely new design with few moving parts, and capable of very accurate predictions. Versions of the albion were created by Simon Tunsted, **John of Gmunden**, and **Johann Müller** (Regiomontanus), and it was influential in the design of the later instruments of **Johannes Schöner** and **Peter Apian**. The *Rectangulus*, made from seven straight rods, rather than the disks and rings of typical armillaries, was an observational instrument that also allowed one to directly transform coordinate systems. Since it was based on straight lines, it could be constructed more easily and accurately, but it was more difficult to read than the armillary or torquetum.

Michael Fosmire

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Richaud, Jean

Born **Bordeaux, Gironde, France, 1 October 1633**
Died **Pondicherry, (India), 2 April 1693**

French Jesuit missionary Jean Richaud made the first astronomical discoveries from India using a telescope. In 1689, he observed that the stars α Centauri and α Crucis are in fact double. (The binary nature of α Crucis had been independently noted by fellow Jesuit Jean de Fontenay, at the Cape of Good Hope, 4 years earlier.)

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Richer, Jean

Born **France, 1630**
Died **Paris, France, 1696**

Giovanni Cassini sent Jean Richer to South America in order to witness the 1672 opposition of Mars. Richer's observations, and those made simultaneously at the Paris Observatory, were used to refine the length of the Astronomical Unit. While in present-day French Guyana, Richer measured that a pendulum swung more slowly than at Paris. He attributed this to weaker gravitational acceleration near the Equator, in accordance with the Newtonian theory of an oblate Earth.

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Riḍwān al-Falakī: Riḍwān Efendi ibn ʿAbdallāh al-Razzāz al-Falakī

Born **Cairo, (Egypt)**
Died **Cairo, (Egypt), 7 August 1711**

Riḍwān Efendi al-Falakī was an Egyptian–Ottoman astronomer known for his production of astronomical tables as well as various instruments and globes. He was also noted for the many students that he trained. There is little information on his birth, youth, and education. However, we know that Riḍwān al-Falakī studied in Cairo and received his astronomical education from distinguished scholars. Indeed, he never left Cairo except in 1680, when he visited Mecca for the *ḥajj* (pilgrimage). Besides writing on astronomy, Riḍwān al-Falakī wrote a number of books on mathematics and geometry. According to the sources on Ottoman astronomy, his works were so abundant that the drafts of his books were considered a camel's load. At the request of the timekeeper Ḥasan Efendi, in 1700 and 1701 he prepared spheres and astronomical devices upon which he marked the Arabic names of stars that he located through observation. Among Riḍwān al-Falakī's many students in astronomy, only Yūsuf al-Jamāli (the servant of Ḥasan Efendi) is known.

The titles of 17 of Riḍwān al-Falakī's astronomical works are known, most of which are extant. All were written in Arabic. Several works are adaptations of the work done at the Samarqand

Observatory under **Ulugh Beg**. His *Zīj al-mufīd ˁalā uṣūl al-raṣad al-jadīd al-Samarqāndī*, or *al-Zīj al-Riḍwānī*, is an astronomical handbook with tables based on *Zīj-i Ulugh Beg* but adapted for Cairo's latitude. It consists of four parts in addition to an introduction and various tables. Riḍwān al-Falakī's *al-Durr al-farīd ˁalā al-raṣad al-jadīd* is possibly a commentary written on Ulugh Beg's *Zīj*; it contains an introduction, 12 sections, and a conclusion. *Asnā al-mawāhib fī taqwīm al-kawākib* is another work he adapted from *Zīj-i Ulugh Beg* for Cairo's latitude.

Riḍwān al-Falakī is also known for his works on timekeeping. Of these, probably the most extensive is *Dustūr uṣūl ˁilm al-mīqāt wa-naṭījat al-naẓr fī taḥrīr al-awqāt*. Other treatises treat eclipses, lunar-crescent visibility, sundials, and Jupiter–Saturn conjunctions. For a listing of his works, see Ihsanoğlu *et al.* (1997), and Rosenfeld and Ihsanoğlu (2003).

Salim Aydüz

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Ristenpart, Frederich Wilhelm

Born **Frankfurt, (Germany), 8 June 1868**
Died **Santiago, Chile, 9 April 1913**

Frederich Ristenpart prepared the master star catalog *Geschichte des Fixsternhimmel* in Germany. However, his failed attempt to modernize the Chilean National Observatory led to suicide. The sad story is recounted by Ashbrook (1984).

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Ritchey, George Willis

Born **Tuppers Plains, Ohio, USA, 31 December 1864**
Died **Azusa, California, USA, 4 November 1945**

George Ritchey may arguably be called the most visionary and yet least appreciated designer and user of large telescopes in early-20th-century America. Although Ritchey has become well known for the Ritchey–Chrétien telescope design, developed along with French astronomer Henri Chrétien, roughly half a century was to elapse before its innovative traits gained widespread acceptance. At the same time, however, Ritchey was among the first astrophotographers to demonstrate the true potential of the modern reflecting telescope. While employed at the Mount Wilson Observatory, California, Ritchey produced remarkable photographs of astronomical objects, especially of the "spiral nebulae." It was in these spiral nebulae, then considered to be merely clouds of gas or dust, that Ritchey discovered faint novae, suggesting that they were in fact galaxies external to the Milky Way. A perfectionist in much of his work, Ritchey was perhaps the foremost optician and instrument maker of his day. Yet, it was also Ritchey's curse that he could be a difficult and sometimes temperamental person to work with. He tended to be secretive and possessive of his techniques, over optimistic in some of his claims, and dismissive of others' ideas. As a result, Ritchey's personal disputes with **George Hale** and others cost him much of his well-deserved reputation.

Ritchey was born into a small farming community. His father was a skilled and, at times, fairly prosperous furniture maker. Although the family had its high and low points, Ritchey succeeded in gaining a reasonably good education for the times. He graduated from Hughes High School in Cincinnati, Ohio (1881), and entered the School of Design at the University of Cincinnati the following year. It was during this time that Ritchey became interested in astronomy, and he was doubtless lucky to be living so near to one of the oldest observatories in America, the Cincinnati Observatory. Between 1882 and 1887, Ritchey was in and out of school as his ambitions to become an astronomer competed with economic reality. He married Lillie May Gray in 1885; the couple was to have two children. While attending classes, Ritchey worked part-time at the observatory, in a small home shop where he built his first telescope, and at the family furniture business. It was for economic reasons that Ritchey left college and became an industrial-arts instructor at the Chicago Manual Training School in 1888. However, the move to Chicago turned out to be Ritchey's great opportunity to become an astronomer.

Ritchey met Hale in 1890, and both realized that they could be of use to one another. Ritchey, who had also taken up photography as a hobby, was an occasional visitor and contract employee at Hale's Kenwood Physical Observatory. The subsequent establishment of the University of Chicago's Yerkes Observatory resulted in Ritchey being hired by Hale as a full-time optician and observer. Both Ritchey and Hale had come to the conclusion that the days of the unchallenged superiority of the refracting telescope were over, and that large reflectors, cheaper to build for their aperture and not susceptible to chromatic aberration, represented the future of large astronomical telescopes.

While still employed at the Chicago Manual Training School, Ritchey worked on a number of projects for Hale, including a 24-in. mirror for a special solar telescope, and perfected his mirror-making techniques on smaller instruments for himself. Ritchey's first major project at the Yerkes Observatory was the construction of a 24-in. $f/4$ Newtonian reflector. This short focal length telescope, expressly built for astrophotography, was considerably "faster" than any normal refracting telescope of the same aperture and much larger than special photographic lenses then available. It had a wide field of view, and could record faint nebulosity with much shorter exposures than competing instruments.

Ritchey proved to be more than just an optician, and with the 24-in. and other telescopes at Yerkes, began his career as an astrophotographer. For a time, he challenged **Edward Barnard** and others with his published photographs of star clusters, nebulae, and the Moon. Many journals and astronomy texts of the time were graced by his photographs. It was during this time that Ritchey began publishing a number of scholarly articles, *e. g*., on his design for an improved mounting system for large telescope mirrors, and reports of his observations, including those changes observed in the nebulosity around Nova Persei (1901). These changes are now considered to be the first observation of a light echo.

Ritchey's next project was a 60-in. reflecting telescope, originally intended for a "western station" of Yerkes Observatory that instead became the Mount Wilson Observatory. It was with the 60-in. that he began his series of photographic observations of the Moon, planets, nebulae, star clusters, and most importantly, the spiral nebulae. In 1910, Ritchey reported that his photographs of spirals (like M81) revealed "soft star-like condensations" that he called nebulous stars. Adopting this condensation model, he concluded that his photographs "strongly oppose, if they do not effectually preclude, the theory that the spiral nebulae are distant systems of stars like our Milky Way." Starting in 1917, however, Ritchey began to discover novae associated with the spirals, and later identified them on plates taken back in 1909. This evidence seemingly contradicted his earlier stance against the spirals as independent stellar systems. As a result, it was largely left to Lick Observatory astronomer **Heber Curtis**, and Mount Wilson Observatory astronomer **Edwin Hubble**, to correctly conclude that the spiral nebulae were in fact external galaxies.

Ritchey's greatest achievement, yet also the project that would see his downfall, was the mirror of the 100-in. Hooker telescope at Mount Wilson Observatory. Construction of this telescope (the largest attempted up to that time) was begun in 1906 but only completed in 1919. The project was plagued with problems and controversies from the beginning. There was considerable difficulty in procuring a high-enough quality glass disk to suit Ritchey, who advocated, and conducted extensive experiments on, the concept of a lightweight, cellular mirror. Ritchey also objected to using a domed observatory, preferring a lightweight, roll-off structure that would eliminate the detrimental effects to atmospheric steadiness caused by the release of heat absorbed by a conventional masonry building during the day. His seemingly endless testing, experimenting, and arguments over design concepts cost him the support of Hale and others. In the end, his personal disputes with Hale also cost him his job at Mount Wilson Observatory and tarnished his reputation in the astronomical community. With the completion of the 100-in. telescope, Ritchey had produced another superb mirror. Yet, he was effectively shut out of Hale's next great telescope project – the 200-in. Mount Palomar reflector. Ritchey was to spend the next several years either working on projects in France, or in semiretirement.

As early as 1910, Ritchey met French astronomer and optician Henri Chrétien. Ritchey and Chrétien recognized the inherent flaws of Newtonian and Cassegrainian optical designs, namely the increase of the aberration called coma toward the edge of the field of view. It causes stars to appear as elongated, comet-shaped blurs. Together, they developed the Ritchey–Chrétien telescope (employing hyperbolic primary and secondary mirrors) that corrected this flaw and potentially produced near-perfect star images in photographs. But Ritchey's loss of reputation, caused by his disputes with Hale, cast serious doubts on the new type of telescope. Given a laboratory at the Paris Observatory, Ritchey completed a prototype of the new design, a 0.5-m (20-in.) reflector, in 1927. Yet, American astronomers virtually ignored the potential benefits offered by the Ritchey–Chrétien design.

In 1930, Ritchey returned to the United States and eventually obtained support to construct a 1-m (40-in.) Ritchey–Chrétien reflector for the United States Naval Observatory. But plagued by poor weather conditions at its original site in Washington, the instrument languished until the telescope was reerected at Flagstaff, Arizona, where its design was thoroughly vindicated. Starting in the 1960s, many of the largest optical telescopes constructed have employed the Ritchey–Chretien design.

Excluded from all aspects of the 200-in. Palomar reflector, Ritchey nonetheless continued to produce designs of giant reflecting telescopes, up to 8-m aperture, none of which was ever built. Yet, he had contributed toward many important developments, both observationally and instrumentally, in early-20th-century astronomy. His principal legacies remain the 60- and 100-in. reflectors at Mount Wilson Observatory. While some of Ritchey's ideas concerning large telescopes seemed radical during his lifetime, many have since come into standard practice in modern astronomical instrumentation. The Ritchey–Chrétien telescope, lightweight cellular mirror, the stress-reducing mirror cell, and even the concept of the "observatory environment," have since been adopted by the astronomical community that, under Hale's influence, had once excluded Ritchey.

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Rittenhouse, David

Born **Paper Mill Run near Germantown, Pennsylvania, (USA), 8 April 1732**

Died **Philadelphia, Pennsylvania, USA, 26 June 1796**

David Rittenhouse, a noted self-educated man of many dimensions, rose from obscure beginnings as a clock- and scientific instrument-maker in Norriton, Pennsylvania, to prominence in the world of science as an effective observational astronomer and experimental scientist.

The origin of Rittenhouse's clockmaking knowledge is unclear, though it is certain that he inherited a chest of tools from a maternal uncle, and that his father purchased the additional tools he originally needed to enter the trade of clockmaking. The tall clocks Rittenhouse made in the roadside workshop he opened in Norriton around 1749, if not unusual in their mechanism, nevertheless were masterpieces of craftsmanship. In three he included small orreries, and in the period 1767–1771 he designed and built two large vertical orreries. One of these was purchased by the Pennsylvania General Assembly for the College of Philadelphia (later the University of Pennsylvania), the other by the College of New Jersey (now Princeton University).

Indeed, it was his clockwork orreries and telescopes that led Rittenhouse to astronomy and ultimately brought him to the attention of the scientific community in Philadelphia. Four years after his marriage to Eleanor Coulston on 20 February 1766, he and his family took up residence in Philadelphia. Eleanor died giving birth to the second of two children; David remarried in 1772, this time to Hannah Jacobs.

However, it was the transit of Venus in 1769 that turned Rittenhouse to serious observational astronomy, and earned him a place among the world's astronomers. He had previously taught himself mathematics and physical sciences by reading, mostly from **Isaac Newton**'s *Principia.* For the transit, Rittenhouse first prepared a proposal to the Philosophical Society in which he recommended that the society establish two stations to observe the transit. He volunteered to equip a station at Norriton as one of the two sites. After the society approved his plan, Rittenhouse constructed a transit telescope (possibly the first telescope made in America), in addition to an equal-altitude instrument and an 8-day clock, all for use at Norriton.

The observational techniques Rittenhouse reported were of greater significance than the data he obtained, more for their inventiveness than for their innovation. For instance, around 1785 he resolved the difficulty in lining up his meridian telescope on a distant mark by installing a collimating lens system enabling him to use a much closer mark. Such a lens system was not new, so he cannot be credited with its origin, but his inventiveness was showcased. The same can be said of his use of spider web in his telescope, for he did not know that it had been previously used by **Francesco Fontana**.

In Philadelphia, Rittenhouse established an astronomical observatory and made many astronomical observations, provided data for almanacs, and lectured on astronomy. In 1786, he published a paper describing his invention and study of a plane transmission grating, in this case a series of closely spaced fine wires wrapped on frames. Using one of these frames he observed up to six orders of diffracted spectra, measured the angular displacement of each, and from the data developed a workable theory of diffraction to account for his observations, but he took the experiments no further. It would be left for **Joseph von Fraunhofer** and Augustin Fresnel to carry them forward.

Rittenhouse also took part in the Mason–Dixon survey of the boundary between Pennsylvania and Maryland (1763), and carried out surveys of other state and colonial boundaries, as well as canals and rivers, usually with instruments of his own construction. He served in various capacities during the Revolution, and in 1792 became the first director of the United States Mint. He was one of the earliest members elected to the American Philosophical Society and succeeded Benjamin Franklin as president of the society (1791). Rittenhouse was elected a foreign member of the Royal Society of London (1795).

Richard Baum

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Ritter, Georg August Dietrich

Born **Lüneburg, (Niedersachsen, Germany), 11 December 1826**
Died **Lüneburg, (Niedersachsen, Germany), 26 February 1908**

August Ritter, a pioneer in the theory of stellar structure, obtained fundamental results by applying the relatively recent laws of thermodynamics, as enunciated by Rudolf Clausius and **William Thomson** (Lord Kelvin), to a gaseous model of the Sun. He took up the problem where **Jonathan Lane** had left it and carried the mathematical development forward to where **Robert Emden** could turn it into a fully developed theory of a perfect gaseous sphere.

The entire subject of solar physics in the period from 1870 to 1890 was in a state of rapid flux, invigorated by the prospect of investigating the physical constitution of the stars by means of spectral analysis. Ritter's highly mathematical contributions, coming from a relatively unknown faculty member at a small polytechnic school, found few appreciative readers at the time.

Ritter began his studies in 1843 at the polytechnic school in Hanover, and continued them at Göttingen University, where he received his Ph.D. in 1853. He then returned to the Hanover polytechnic school as an instructor in 1856. Ritter was subsequently appointed a professor of mechanics at the Aachen Technische Hochschule when it opened in 1870. Some idea of his circumstances there is suggested by the testimony of Otto Lehmann, who came to Aachen in 1883 from the larger secondary school at Mühlhausen. The space for research at Aachen was so small that Lehmann could not find room for the limited apparatus he brought with him. It took him far longer to do research at Aachen, he claimed, but he felt compensated by the increased time he had there for research.

In a series of 18 papers published between 1878 and 1883 in the leading German physics journal, *Annalen der Physik*, and in a separate textbook of 1879, Ritter employed a meteorological model to derive the fundamental differential equations regulating both a thermodynamically stable gaseous sphere heated by gravitational contraction and one subject to cyclical pulsations. He showed that stable convective currents acting throughout the sphere produced a temperature gradient inversely proportional to its radius.

A 1939 assessment by **Subrahmanyan Chandrasekhar** characterized Ritter's investigations as "a classic [,] the value of which has never been adequately recognized," in which "almost the entire foundation for the mathematical theory of stellar structure was laid by him" (1939, pp. 178, 179). Astronomers **Otto Struve** and Velta Zebergs pointed out that Ritter's 1879 paper on the theory of radial pulsations in stars was advanced long "before the [observed] variation in radial velocity [among classical Cepheids] was known." More importantly, Ritter had derived a "relation between density and period of pulsation" that "remarkably closely approximates the observations" (1962, p. 314).

Michael Meo

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Struve, Otto and Velta Zebergs (1962). *Astronomy of the 20th Century*. New York: Macmillan.

Ritter, Johann Wilhelm

Born **Samitz, (Chojńow, Poland), 16 December 1776**
Died **Munich, (Germany), 23 January 1810**

German chemist, physicist, and physiologist Johann Ritter came to work at Jena with **Alexander von Humboldt** in 1795. His subsequent career and life were brief and chaotic, partially owing to issues of philosophy of science then under bitter discussion in Germany. In 1801, while at the court of the Duke of Gotha and Altenberg, Ritter discovered that paper soaked in a solution of silver iodide was blackened most by the radiation coming from the Sun just slightly off the end of the spectrum beyond the last visible violet light. Ritter was, therefore, the discoverer of ultraviolet radiation, the year after **William Herschel** discovered infrared from its heating power.

Virginia Trimble

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Porter, Roy (ed.) (1994). 'Ritter.' In *The Biographical Dictionary of Scientists*, 2nd ed., p. 583. New York: Oxford University Press.

Roach, Franklin Evans

Born **Jamestown, Michigan, USA, 23 September 1905**
Died **Tucson, Arizona, USA, 21 September 1993**

American spectroscopist and photometrist Frank Roach was for many years the world expert on how bright the sky is at night and the various sources that contribute to the brightness. He was the oldest of four children of optometrist Richard F. Roach and Norwegian immigrant Ingeborg (*née* Torgerson) Roach and was educated in the public schools of Wheaton, Illinois (including the high school also attended by **Edwin Hubble** and **Grote Reber**), and Highland Park, California. Roach started on a premedical curriculum at Wheaton College, and won a scholarship to the University of Michigan, but decided to use it to finish a bachelor's degree immediately rather than a medical degree involving a longer period of education that his family could ill afford. A succession of temporary, nonscientific jobs continued to interrupt Roach's education, but he succeeded in completing, at the University of Chicago, an MS in 1930, with a thesis on absorption lines of ionized sulfur in stellar spectra and a Ph.D. in 1934 with a thesis on red and near-infrared stellar spectra, both under the direction of **Otto Struve** who had, in 1932, succeeded **Edwin Frost** as director of Yerkes Observatory. In 1932, Roach was sent to Perkins Observatory, Ohio, where he used their 69-in. telescope to develop and use a spectrograph intended for the new McDonald Observatory, a Chicago–Texas collaboration.

Roach was appointed as the first astronomer stationed at McDonald Observatory and, while there, collaborated with **Christian Elvey** on photographic photometry of reflection nebulae, his first venture into accurate measurements of faint, extended sources. During his time as associate professor of astronomy at the University of Arizona, beginning in 1936, Roach continued both stellar spectroscopy (mastering the details of atomic physics essential for understanding diffuse skylight) and photometry with Elvey. During World War II, Roach was first a member of the California Institute of Technology rocket program, working at Eaton Canyon near Pasadena and then at what became the United States Naval Ordnance Test Station [NOTS], China Lake. Though he was reassigned to work on high-explosives research in connection with the Manhattan Project, Roach returned to NOTS after the war, where he established with Elvey a pioneering night-sky research group. After a year in Paris (1951/1952) collaborating with **Daniel Barbier**, the French expert on night-sky emission, Roach moved to the National Bureau of Standards [NBS], in Boulder, Colorado. He established, in 1961, another night-sky observatory on Mount Haleakala, in Hawaii, and moved there after his 1966 retirement from the NBS.

Roach provided the standard photometer against which all the others were calibrated during the International Geophysical Year (1958), acted as an advisor to astronauts on what they could reasonably expect to see in space and how to interpret it, and was part of the scientific team for the "Scientific Study of Unidentified Flying Objects" conducted by the University of Colorado in 1967, under contract to the United States Air Force.

Roach's greatest achievement, however, remained the identification of the various sources of diffuse skylight. These include the glow of ionized atoms in the Earth's atmosphere (in layers that, as he showed, moved up and down through the day and night and the seasons), aurorae (atomic glows driven by particles coming from solar flares), faint stars, and sunlight reflected by dust in the plane of the Solar System (zodiacal light). His 1973 book, *The Light of the Night Sky*, written with Janet L. Gordon (who had been part of the University of Arizona astronomy department during his time there), continues to be cited on the subject. Unfortunately, of course, the skies we see now are very much brighter than those Roach measured because of the increased input of artificial light, reflected back by high-lying dust (some of which is also artificial). In the course of his career, Roach published more than 100 papers.

Gordon and Roach were married in 1977, following the death of his first wife, Eloise Blakslee, who had been the daughter of a Yerkes Observatory photographer. Roach received a Department of Commerce Gold Medal in recognition of his outstanding work on upper-atmosphere physics.

Nadia Robotti and *Muttco Leone*

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Roberts, Alexander William

Born **Farr, (Highland), Scotland, 4 December 1857**
Died **Alice, (Eastern Cape), South Africa, 27 January 1938**

Using light curves he derived from his own very precise visual photometry, Alexander Roberts pioneered the computation of eclipsing binary-star orbits, shapes, and densities. Roberts demonstrated, simultaneously with **Henry Norris Russell**, that the components of some of these stellar systems are tenuous, low-density stars with gigantic diameters.

Roberts's father apparently died while Alexander was an infant as only his mother's maiden name, Ann Campbell, is known. The family moved from Farr to Leith, where Roberts received his education at the Saint James Schools, and further preparation for a career in teaching at Moray House and the Watt Institution and School of Arts. After completing his education, in 1878 Roberts accepted a teaching post at Wick, Caithness, where he apparently met his future wife, Elizabeth Dunnett. In 1881, he matriculated at the University of Edinburgh for further education.

At an early age, Roberts read a copy of **James Ferguson**'s *Astronomy Explained on Sir Isaac Newton's Principles* and thereafter contemplated an astronomical career. In 1882, he applied for a position as an assistant at the Edinburgh Observatory, but in response received a discouraging letter from **Charles Smyth**, the Astronomer Royal for Scotland. Instead, after graduating from the university, Roberts accepted a call to missionary teaching at the Free Church Mission College in Lovedale, Cape Colony, South Africa. Roberts arrived at Lovedale in July 1883 and was followed a year later by Elizabeth; they were married in 1884 and had three children.

After settling in Lovedale, Roberts took up his avocational interest in astronomy. After some preliminary recreational observing, he made an accurate determination of the latitude of his observing station. The next step of his orientation was to map the night skies, which he did carefully with an old theodolite and binoculars. Roberts noted not only the position of each visible star but also numbered each star in a sequence that represented their relative brightness. In this familiarization process, Roberts revisited each chart a day, a week, or a month later, each time reranking the stars according to their brightness. Using this process he discovered a number of new variable stars. By 1891, when construction of his observatory was completed, Roberts's orientation to the southern night skies was also complete, and he began to pursue serious astronomical research. With the encouragement of **David Gill**, director of the Royal Observatory, Cape of Good Hope, Roberts began to observe southern variable stars. By 1894, he had discovered a number of additional variable stars so that the total of his discoveries had grown to 20. As the number of known variable stars in the southern skies grew, Gill recommended that Roberts pay particular attention to eclipsing binary stars, of which Algol was the best-known example.

As his observing program matured, Roberts considered the conditions that might influence the accuracy of his observations, for example, the effect of position angle of the variable star and comparison stars in the field of view, and also the influence of relative proximity to the variable star and the comparison star in the field of view to his nose. After these effects were noticed, Gill arranged for the donation of a special photometer by Sir John Usher. Roberts conducted an exhaustive series of observations with this special photometer in which the field of view could be rotated to six different fixed positions. Using the Usher photometer, then a wedge photometer on loan from Oxford University, and later a 4-in. meridian photometer on loan from Harvard College Observatory, Roberts conducted his variable star photometry program with unprecedented levels of precision for visual observations.

For nearly 30 years, Roberts was among the most prolific and exacting variable star observers in either hemisphere. Roberts determined the orbital elements and absolute dimensions of eclipsing binaries from an analysis of their light curves. Because of his confidence in the precision of his light curves, Roberts took the extra steps necessary in computing the orbits of binary stars to demonstrate that their shape was that of oblate spheroids as had been suggested theoretically by **George Darwin** and **Jules Poincaré**. Roberts took the process a step further, and computed the relative diameters and masses of the individual stars in some of these systems. From these data, he concluded that the stars were distended and tenuous objects. In contrast, Russell reached similar conclusions based only on the combined mass of the binary pairs and did not venture the computation of the masses of individual stars.

Roberts's style of reporting for his results was to prepare accurate light curves reflecting his observations, and to draw theoretical conclusions based on his mathematical analysis of the light-curve data. Thus his reporting, in the leading astronomical journals of the times, was fairly compact and did not include his reduced observations. Eventually, Roberts had accumulated over a quarter of a million observations; professional colleagues urged him to publish his reduced data. Around 1915 or so, the reality of his dilemma began to sink in. In order to accommodate requests, from the likes of **Edward Pickering** and **Ejnar Hertzsprung**, Roberts would have to give up observing and spend his full effort at reduction and tabulation of his results. The data reduction effort was as monumental as the effort that had been invested in making the observations. At Pickering's request, Roberts prepared his observations for publication, but unfortunately the format in which he presented his data was not acceptable to Harvard College Observatory for publication in their *Annals*. Though he appealed for assistance from Pickering, Hertzsprung, and others, Roberts insisted that the work was his alone; he was unwilling to train natives to help with this effort, likely for lack of the financial resources with which to pay them for their work. Tragically, Roberts's massive accumulation of data remained unpublished at the time of his death. The data are now held by the American Association of Variable Star Observers and will eventually be reduced and added to their archives, a fitting home for this valuable resource. Well known in the field of binary-star astronomy in his era, Roberts's published work is well cited by authorities in and after his time including **William Campbell** and **Zdněk Kopal**.

In 1893, Roberts was placed in charge of a 3-year program for training South African born teachers in a new normal school at Lovedale. Over the next 27 years, he trained over 4,000 natives, and became well known throughout the colony as a result of the efforts of this large corps of teachers. Through these extensive contacts, Roberts became increasingly involved in South African race relations. In 1920, South African Prime Minister Jan Smuts appointed Roberts to represent the interests of native Africans in the all-white Senate, which Roberts did with distinction. Roberts also served on a number of commissions investigating various problems including a racially charged riot in Port Elizabeth and the Bondelzwarts rebellion in southwest Africa. While the 1920s saw the end of Roberts's own astronomical research, he used his position in government to support the establishment of the University of Michigan's Lamont-Hussey Observatory at Bloemfontein. He also worked to promote astronomy among South Africans. He lectured widely and corresponded with young enthusiasts. **Alan Cousins** was one of the future South African astronomers inspired by Roberts's personal influence.

The first recipient of an honorary Doctor of Science degree from University of the Cape of Good Hope (now the University of South Africa), Roberts was also elected fellow of the Royal Astronomical Society, the Royal Society of Edinburgh, and the Royal Society of South Africa. He served as president of the South African Association for the Advancement of Science in 1913, as president of the Astronomical Society of South Africa in 1927 and 1928, and as a South African delegate to the 1925 International Astronomical Union General Assembly held at Cambridge, England.

Roberts's personal papers are deposited in the Cory Historical Library of Rhodes University.

Keith Snedegar

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Roberts, Isaac

Born **Groes, (Clwyd), Wales, 27 January 1829**
Died **Crowborough, (East Sussex), England, 17 July 1904**

Isaac Roberts, a pioneer astrophotographer, demonstrated that long exposures in large, well-mounted reflecting telescopes could record details of nebulae not visible to the naked eye. His photographs of the Andromeda, Orion, and many other nebulae surpassed all prior efforts.

The son of a farmer, Roberts moved with his family to Liverpool, England, where his father, William Roberts, took a position as bookkeeper in 1835. Roberts received only an elementary education. The remainder of his great store of knowledge was self-acquired.

In 1844, Roberts was apprenticed to a local building firm for a period of 7 years. After his apprenticeship, he remained with the firm, eventually becoming its manager. When the owners of the firm died, Roberts was retained by the families to supervise the closing of the company. Roberts then opened his own building firm, enjoying considerable success as a hard-working and diligent businessman. He took every possible opportunity to increase his knowledge, principally by means of study at the Mechanics Institute, which emphasized natural philosophy and experimental methods of investigation. In 1875, he married Ellen Anne Cartmell; their marriage was childless and ended by her death. By 1888 Roberts had amassed sufficient funds to retire. He then began to take part in the scientific work which had long fascinated him.

Interested in geology during his working days, Roberts became a fellow of the Geological Society, and wrote several papers that are still of interest today. But after a few years, he turned to astronomy and worked in that field for the remainder of his life.

Astrophotography was not new when Roberts came upon the scene. But, in 1878, when dry photographic plates were introduced, Roberts was among the first to realize the implications of the new emulsion for astronomy. An astronomical photograph need not end when all of the stars and nebulous details visible to the eye are recorded. The exposure could be continued, with more light accumulated on the plate to register fainter objects.

In 1879 Roberts purchased a 7-in. Cooke refractor, which he mounted in his private observatory at Maghull, near Liverpool. He began his experiments in astrophotography with this telescope. At first he intended to produce a photographic star atlas, and toward that end attended the 1887 organizational meeting for the *Carte du Ciel* project in Paris. The magnitude of the effort impressed Roberts, but he eventually decided not to participate in it.

At this time, **Andrew Common** had produced a magnificent photograph of the Orion nebula that won a Gold Medal from the Royal Astronomical Society [RAS] in 1884. Unfortunately, no one seemed to be following up in this exciting new field. Since Roberts had achieved some success in photographing nebulae and clusters, he decided that this avenue was the one through which he could make the most effective contribution.

Roberts ordered a 20-in. silver-on-glass reflector from the firm of **Howard Grubb**. The 100-in.-focal-length instrument was mounted equatorially with a very accurate clock drive. Plates were exposed at the mirror's prime focus, in order to preserve as much light as possible. Roberts added a novel touch to the mounting. In the place of a counterweight, he mounted the 7-in. refractor. It was an odd-looking arrangement, but it worked, and Grubb sold several other instrument-pairs in this style.

After a lengthy period of adjustment, the photographic results began to flow. The first exceptional images were of the Orion nebula and the Pleiades. The Orion exposure revealed more detail and extended the image to six times the area of Common's prize-winning picture. The image of the Pleiades revealed photographically, for the first time, the nebulosity that envelopes this brilliant cluster. Roberts exhibited these images at the January 1886 meeting of the RAS. He reported having taken over 200 images of objects outside the Solar System during 1885. For 15 years, Roberts regularly exhibited his latest photographs at the RAS meetings.

Roberts was active in the organization of astronomers during this period. He played a role in the formation of the Liverpool Astronomical Society [LAS], but objected to the rapid expansion of that organization into one of worldwide scope. He withdrew from active participation in the LAS, but was later active in the formation of the British Astronomical Association.

Roberts's greatest photographic achievement was a 4-hour exposure of the Andromeda nebula (known today as the Andromeda Galaxy). This image was presented to the RAS in 1888. It recorded photographically, for the first time, the spiral nature of the nebula. The image caused quite a sensation. It compares well with modern images of this galaxy. Though he did not know it, he had resolved a number of individual stars in the gigantic spiral.

In 1890 Roberts moved to Crowborough, Sussex, seeking a location with more favorable observing conditions. The new observatory was 780 ft. above sea level. He found the atmosphere to be much steadier at Crowborough. At the new location, Roberts employed a professional astronomer, **William Franks**, as his observer; and most of the observational work at Crowborough was carried out by Franks.

In 1896, Roberts went on an eclipse expedition to Norway. His party did not see the eclipse, but while on the trip he did meet **Dorothea Klumpke**, a San Francisco native and a professionally trained astronomer working on the *Carte du Ciel* project at the Paris Observatory. Roberts and Klumpke were married in 1901. The second Mrs. Roberts moved her professional astronomical activities to Roberts's observatory at Crowborough. The two collaborated on astronomical projects, mainly the analysis and publication of his plates, until Roberts's death.

Roberts died suddenly. On the morning of his death he had been working on his plates. Four years later his ashes were entombed in a stone monument in Birkenhead cemetery near Liverpool. The monument is fascinating; it includes engravings of some of his most important photographs. After settling his estate, Dorothea returned to Paris, where she continued to be active in astronomy. She maintained control of Roberts's photographic plates, making them available to other astronomers for research purposes. In 1928, to commemorate the centenary of Roberts's birth, she published a two-volume photographic atlas based on his work.

The failure of the Great Melbourne Telescope in the 1860s had cast a pall over the suitability of the reflecting telescope for astronomical work. However, over the years, Roberts had the opportunity to experiment with many cameras and telescopes. He saw that the future of observational astronomy lay with big reflectors, and took every opportunity to describe and explain this fact to other astronomers. By the time of his death, his assertions had borne fruit not only through his own work, but also that of **George Ritchey** with his 24-in. Newtonian reflector at Yerkes Observatory, and **James Keeler** with the 36-in. Crossley Reflector at Lick Observatory. The giant instruments erected by Ritchey and **George Hale** at Mount Wilson Observatory bore witness to the value of Roberts's early assessment of the reflector's potential, as did the welter of smaller reflectors installed in most contemporary observatories in the first half of the 20th century. Roberts's work played no small part in this revolution.

Roberts was an avid musician. He sang with the Liverpool Philharmonic Choral Society. He was fluent in the Welsh language. Toward the end of his life he became an agnostic, expressing the view that revealed religion had no place in the Universe that he had explored. Politically, Roberts was a liberal, and he was active in education reform.

During his career as a scientist, Roberts received numerous medals and honors. Among these were election to the Royal Society (1890), an honorary Doctor of Science from Trinity College, Dublin (1892), and the Gold Medal of the Royal Astronomical Society (1895). A crater on the Moon has been named Roberts to honor both Isaac Roberts and **Alexander Roberts**, a South African amateur variable star astronomer.

Leonard B. Abbey

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Robertson, Howard Percy

Born **Hoquiam, Washington, USA, 27 January 1903**
Died **Pasadena, California, USA, 26 August 1961**

American mathematical physicist Howard ("H.P.") Robertson is honored by the names of the Poynting–Robertson effect (of light on small dust particles) and the Robertson–Walker metric, which describes the curvature of space–time within the framework of general relativity. He was the oldest of five children of a family of modest means, whose father died when he was 15. Nonetheless, all the children attended the University of Washington, where Robertson earned a bachelor's (1922) and a master's (1923) degree.

At the University of Washington, Robertson came under the tutelage of the famous mathematician and relativist, Eric Temple Bell. They had a tempestuous and engaging intellectual relationship, which they both valued highly over the years.

Two years later, Robertson obtained his Ph.D. from the California Institute of Technology (Caltech). His thesis was entitled "On Dynamical Space–times which contain a Conformal Euclidean 3-space," and ran a mere 38 pages in length. While at Caltech, he interacted with the mathematical physicists, Paul S. Epstein and Harry F. Bateman.

The next 2 years were spent studying in Göttingen and Munich, Germany as a National Research Fellow. Robertson returned to Caltech as an assistant professor in 1927. From 1929 to 1947 he was at Princeton University, again returning to Caltech as a professor in 1947. From 1940 to 1943, Robertson served with the National Defense Research Council, and was with the London Mission of the Office of Scientific Research and Development from 1943 to 1946. From 1944 to 1947, he was an expert consultant to the Office of the Secretary of War. He was awarded the United States Medal of Merit in recognition of his wartime services to his country.

After World War II, Robertson was a much-sought-after scientific advisor to numerous branches of government and industry, and he was very effective in applying science to military strategy and tactics. In this capacity he was the chief scientific advisor to general M. Gruenther, then the Supreme Allied Commander in Europe (1954–1956). From 1956 to 1960, Robertson was a member of the Defense Science Board. He was also the chief science advisor to the second and third directors of the Central Intelligence Agency, admiral Sidney W. Souers and general Hoyt S. Vandenberg. Robertson was a trustee of the Systems Development Corporation, the Institute for Defense Analysis, and the Carnegie Endowment for International Peace. He was also a director of the Northrop Aviation Corporation.

Robertson was endowed with exceptional mathematical powers coupled with a deep insight into physical processes. His early scientific efforts were concerned with the study of differential geometry, in which he was strongly influenced by the work of Bell, Luther Eisenhart, Oswald Veblen, and **Herman Weyl**. In 1931, for example, he translated Weyl's classic tome, *The Theory of Groups and Quantum Mechanics*, into English. He also published works on quantum mechanics, notably a short paper in *The Physical Review* pointing out the connection between uncertainty in the simultaneous measurement of two noncanonical variables and the commutation properties of their associated operators (1929). He also made a seminal contribution (1940) to T. von Karman and L. Howarth's theory of isotropic turbulence by applying invariant theory to the categorization of the velocity correlation tensors that feature prominently in their equations.

Robertson's best-known contributions were in the theory of relativity and its applications to cosmology. He developed the theory of uniform cosmological spaces, *i. e.*, spaces with spatial isotropy and homogeneity, and deduced the form of the line element common to all these spaces (1929). These have subsequently been called Robertson–Walker spaces. Robertson was deeply intrigued by the consequences of the observed red shift–distance relationship, which led to an extensive and long-lasting working association with **Edwin Hubble**, **Milton Humason**, and **Richard Tolman**.

Robertson is also well known for his work on the absorption and re-emission of light by a particle revolving around the Sun (1937). His fully relativistic treatment of the problem superseded **John Poynting**'s (1903) classical formulation, and in fact led to a significant quantitative correction to the classical result. Robertson's calculations indicated the presence of a tangential drag that acts to reduce the angular momentum of the body, causing it to spiral in toward the Sun. The effect is important for small dust particles, and implies that the immediate neighborhood of the Sun should be cleared of these particles on astrophysically interesting timescales. This process is commonly referred to as the Poynting–Robertson effect.

Robertson had a long-standing fascination with sports cars, and was well known for his fast driving on the Caltech campus and in the surrounding area. In early August of 1961 he was involved in a high-speed automobile accident. He died from a pulmonary embolism brought on by the injuries sustained in the accident.

Thomas J. Bogdan

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Robinson, Thomas Romney

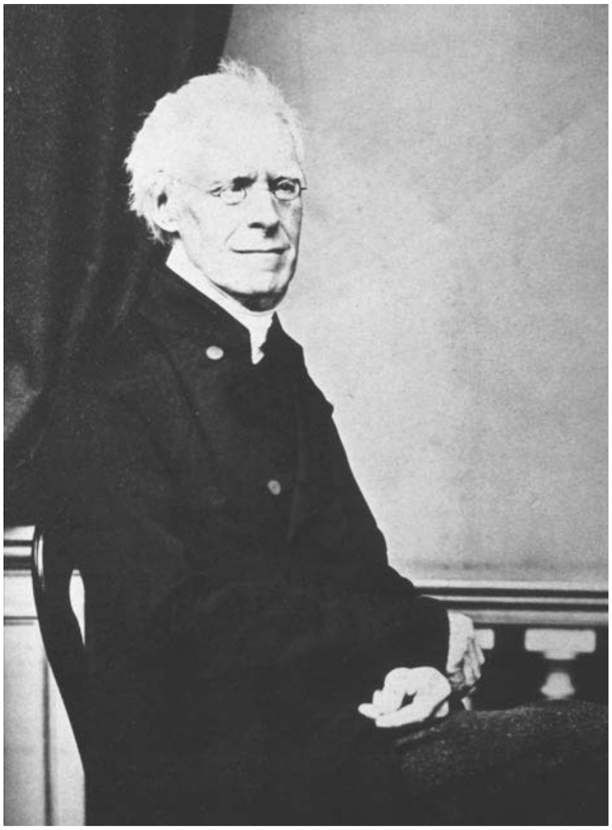
Born **probably Lawrencetown near Bainbridge, Co. Down, (Northern Ireland), 23 April 1792**
Died **Armagh, Ireland, (Northern Ireland), 28 February 1892**

Thomas Romney Robinson (sometimes John Thomas Romney Robinson) was director of Armagh Observatory for more than 58 years. A child prodigy, he became one of the most respected practical astronomers of his time. He is remembered for the anemometer design that bears his name.

Romney Robinson (as he is commonly referred to) was the eldest son of Thomas Robinson, an English portrait painter, and his wife Ruth Buck. Thomas named his son after his mentor, George Romney, and set up business in Dublin about 1790. Later the family moved to County Down, and then in 1801 settled in Belfast where Romney attended Belfast Academy.

Robinson was precocious, being able to read poetry by three and to write verse by five. By the age of 12 a volume of his poems was published in Belfast with a list of 1,600 subscribers. He showed an interest in the machinery used in the linen and shipbuilding industries and experimented with chemistry and electricity. Robinson entered Trinity College, Dublin, in January 1806 and graduated in 1810, the year of his father's death. He gained fellowship in 1814. Robinson was elected a member of the Royal Irish Academy in 1816 and read papers on high-temperature furnaces and electricity. He lectured in Trinity College as deputy to Bartholomew Lloyd, the professor of natural and experimental philosophy, and provided his students with a useful textbook in his *System of Mechanics* (1820).

However, Robinson found that teaching left him with little time for research. He was a close friend of **John Brinkley**, the Andrews' Professor of Astronomy and director of Dunsink Observatory. In 1821 he relinquished his fellowship, married, took holy orders, and became the rector of the parish of Enniskillen, County, Fermanagh. In 1823 Robinson was appointed director of Armagh Observatory, and the following year he was appointed vicar of the parish of Carrickmacross, which was closer to Armagh.



Armagh Observatory had been established by the (Anglican) Church of Ireland in 1790 but had not attained much distinction under its first two directors, James Archibald Hamilton and William Davenport. Robinson set the observatory on a productive course. Thanks to the generosity of the primate, Lord John George Beresford, Robinson was able to commission badly needed new instruments. He ordered a transit instrument and a mural circle from Thomas Jones, a leading London instrumentmaker. The new transit was in place by 1827, and observations began on a program of positional measurements. The publication of the transit observations for the years 1828, 1829, and 1830 was funded by Beresford. The mural circle was delivered in 1831 but did not come into operation until late in 1834.

The third instrument that Robinson commissioned was a 15-in. reflecting telescope of an innovative design, which was highly significant for the future development of telescope technology. It was a Cassegrain, rather than a Newtonian, telescope, then the standard. It was the first large reflecting telescope to be mounted equatorially with a clock drive. The primary mirror of speculum was supported by a novel lever support system to avoid distortion. The maker was **Thomas Grubb** who, as engineer to the Bank of Ireland in Dublin, was well known for his machines for printing banknotes. Early in 1833, Robinson approached Grubb to see if he would make an equatorial mount for the 13.3-in. objective by Chauchoix of Paris, which had been purchased by **Edward Cooper** for his private observatory at Markree Castle, County Sligo. Cooper's telescope was installed in April 1834, and the 15-in. telescope was installed at Armagh Observatory the following year. With the staunch support of Robinson, Grubb and his son **Howard Grubb** went on to establish a telescope-making firm of international renown.

Robinson was closely associated with **William Parsons**'s ambitions to build large reflectors at Parsonstown (Birr). In November 1842, accompanied by his friend Sir **James South**, Robinson witnessed the casting of the speculum mirror for the great 6-ft. telescope and described the scene in graphic detail in the *Proceedings* of the Royal Irish Academy. He advised Rosse to adopt an equatorial mount but the latter opted for a universal joint arrangement that was less demanding mechanically.

By February 1845 the great telescope was nearly finished, and Robinson returned to Birr, accompanied once again by South. After waiting for fine weather, the first observations were made on 10 March, and 40 nebulae from **John Herschel**'s catalog were examined. The following month, Robinson reported in glowing terms on the performance of the telescope to the Royal Irish Academy.

Robinson's experience of observing with large telescopes at Birr convinced him that there was a need for a large reflector in the Southern Hemisphere. In 1849, when Robinson was president of the British Association, the association proposed that the government should provide the Cape Observatory with a large reflector. A Southern Telescope Committee was formed, and a proposal for a 4-ft. Cassegrain reflector by Grubb on a German equatorial mount was made in 1853, but was rejected by the government. The project was revived in 1862 when the State of Victoria in Australia decided to erect a large telescope in Melbourne. After prolonged negotiations, which also involved the offer of a gift of a telescope from **William Lassell**, the State of Victoria ordered the telescope from Grubb in February 1866. The telescope was built in Dublin and delivered to Melbourne in 1869. Unfortunately, the resources of the Melbourne Observatory were not sufficient to maintain the speculum mirror in proper condition, and this, combined with other factors, led to disappointing results.

Meanwhile, Robinson, with the help of assistants, had maintained a strenuous program of meridian observations. This culminated in 1859 in the publication of *Places of 5,345 Stars Observed from 1828 to 1854 at the Armagh Observatory* printed at government expense. For this work, Robinson was awarded the Royal Medal of the Royal Society in 1862.

One early investigation pursued by Robinson was the determination of the exact longitude of the Armagh Observatory. In 1838 he organized a comparison of the longitude of the Greenwich, Dunsink, and Armagh observatories by transporting 15 chronometers between the 3 locations. The following year, he compared the longitudes of Armagh and Dunsink by firing rockets from the summit of an intervening mountain to synchronize observations at the two observatories.

In 1845, the meridian program at Armagh was threatened by a proposal to build a railway link between Armagh and a neighboring town. As the railway line would pass within 160 yards of the transit instrument; Robinson was concerned that vibration would interfere with the accuracy of the observations. Robinson strenuously opposed the proposal, and the railway was prohibited from approaching within 700 yards of the observatory. Robinson was one of the first of observatory directors to have to deal with this sort of problem, and his expertise was later called upon in similar situations.

Regular weather observations were part of the observing routine at Armagh Observatory from its foundation, and the erection of a wind gauge was proposed in 1839. Robinson reviewed previous designs and, acting on an idea suggested to him many years earlier by Richard Lovell Edgeworth, he constructed a horizontal windmill with four hemispherical cups, and described it to the British Association in 1846. He continued to refine his anemometer, and an improved version was described to the Royal Irish Academy in 1855.

In his later years at Armagh, Robinson had to cope with declining financial resources as a result of the disestablishment of the Church of Ireland and the reduction in rents from lands owned by the observatory. This situation reinforced his conservative political views and led to his vigorous opposition to Irish political reform.

Robinson was an eloquent and forceful speaker and soon came to prominence as a public man of science. He regularly attended meetings of the British Association for the Advancement of Science and played a central role in bringing the association to Dublin in 1835. He served as president of the Royal Irish Academy from 1851 to 1856 and played an important part in securing new premises for the Academy in 1851. Robinson was elected a fellow of the Royal Society in 1856 and awarded honorary degrees by the Universities of Dublin, Oxford, and Cambridge. The 24-km-diameter lunar crater at 59°.0 N and 45°.9 W is named in his honor.

Robinson married twice. His first wife was Eliza Isabelle Rambaut of an Irish Huguenot family, and they had three children. Eliza died in 1839. In 1843 he married Lucy, youngest child of Richard Edgeworth and half-sister of Maria, the novelist. Robinson's daughter by his first marriage, Mary Susanna, married the Irish mathematical physicist **George Stokes**, with whom Robinson corresponded regularly on scientific matters.

Ian Elliott

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Roche, Édouard Albert

Born **Montpellier, Hérault, France, 17 October 1820**
Died **Montpellier, Hérault, France, 18 April 1883**

Édouard Roche is remembered for the study of equipotential surfaces, called Roche lobes, and calculation of the distance from a planet at which satellites will be torn into rings, called the Roche limit.

Roche continued a tradition in his family, whereupon several members became professors at the University of Montpellier. There, he earned his *docteur ès sciences* degree in 1844 but spent the next 3 years at the Observatoire de Paris, working under **Dominique Arago**. While at Paris, Roche was introduced to **Urbain Le Verrier** and **Augustin Cauchy**.

In 1849, Roche accepted the position of *chargé de cours* at Montpellier and in 1852 was appointed professor of pure mathematics. The relative isolation of Montpellier likely helped foster the emergence of Roche's original ideas. He was elected a corresponding member of the Académie des sciences in 1873, but was later denied full membership in the organization. Roche's life was afflicted by poor health; he was forced to take a leave of absence in 1881 and succumbed to a lung inflammation.

Roche devoted himself to topics that lay generally outside of mainstream astronomical research in his time. He studied the equilibrium figure of a rotating fluid body that was subjected to an external gravitational force caused by another body. This condition is extremely important for determining the equipotential surfaces around a pair of point masses like a binary star. Where one (or both) of the components assumes a tear-drop shape, the space(s) so filled is called the Roche lobe. Related to this investigation was Roche's calculation of the minimum distance at which a satellite (of equal density) may revolve above its parent planet. The boundary, inside of which the tidal forces are strong enough to disrupt the satellite into smaller pieces, is called the Roche limit. This condition plays a crucial role in the formation of planetary-ring systems.

Roche likewise explained the streamlined shapes of cometary envelopes, under the assumption of a repulsive force originating in the Sun that diminished with the square of its heliocentric distance. His theoretical explanation was offered decades before such radiation pressure was discovered in the form of the "solar wind." In turn, Roche presented a thorough analysis of the "nebular hypothesis" of **Immanuel Kant** and **Pierre de Laplace**. His investigation brought a decided coherence to the notion before it was challenged by rival cosmogonic theories. Roche's treatment of the internal density distribution of the Earth, with appropriate modifications, is still of value today.

Zdeněk Kopal (1989, p. 2) has written that Roche's principal accomplishments "were too far ahead of their time to be appreciated fully."

Martin Solc

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Roeslin, Helisaeus

Born **Plieningen, (Baden-Württemberg, Germany), 17 January 1545**
Died **probably Haguenau, (Bas-Rhin, France), 14 August 1616**

Helisaeus Roeslin was one of the first to recognize that comets are astronomical bodies rather than atmospheric bodies and, with **Nicholas Bär** (Raimarus Ursus) and **Tycho Brahe**, formulated a geo-heliocentric model of the planets. Roeslin studied astronomy and medicine at the University of Tübingen from 1561. Samuel Eisenmenger (Siderokrates) became his teacher in astronomy, astrology, and alchemy. Roeslin finished his studies in 1569 with the degree of a doctor of medicine. He joined Eisenmenger in the employ of the Markgraf von Baden. Influenced by Eisenmenger, Roeslin devoted himself to the spiritualistic theory of Kaspar von Schwenkfeld, but showed religious tolerance during his whole life. In 1569 he became physician in Pforzheim, married, and became an employee of the Pfalzgraf von Pfalz Veldenz. There Roeslin became a well-known doctor. From 1582 onward he was physician in the city of Haguenau.

Roeslin's astronomical interests rose with two events, the supernova of 1572 (SN B Cas) and the great comet of 1577. He developed a theory of the comet that placed it first in the Earth's atmosphere. Later he withdrew this idea and agreed with the theory of **Christoph Rothmann** and Brahe, in which comets belong to the sphere of the planets. In his publication in 1597 he explained the nature of comets as heavenly bodies in the sphere of the planets. Roeslin claimed that comets are not atmospheric phenomena and that this is in clear contradiction to **Aristotle**'s ideas. With the observation of comets there is no way to maintain the idea of the unchangeable heavenly regions and their perfection and divinity. The tail of a comet he explained as light focused by the comet itself.

Therefore, for Roeslin, comets are "secondary stars," which have not been created during the "first 6 days of the world," but were "born" later. Also, they are not permanent bodies and after some time of visibility they disappear again. Moreover, comets move in circular orbits around the Sun, but not only in the zodiacal belt. With this work, Roeslin gained major significance in the history of cometary science. He is one of the first astronomers who spoke clearly of regular orbits of comets. Roeslin's opinion was contrary to the widely held views of Rothmann, Brahe, and **Johannes Kepler**. His works from 1597 and 1609 are quite significant, because the theory of comets as heavenly bodies was written in German for the first time, and he also clearly pointed out the contradiction to the physics of Aristotle.

Among Brahe, Bär, and others, Roeslin developed the idea of a geo-heliocentric system (*De opere Die creationis*, 1597), which only differs from the others in details. Roeslin still considered the planets to be fixed on spheres with no space in between. The example of Roeslin shows how widespread the theory of geo-heliocentricity was at that time. Roeslin and Kepler had several public debates, but Kepler did not succeed in convincing Roeslin of the heliocentric system. They reconstructed different birth dates of Jesus Christ (Roeslin 1.25 years BCE, Kepler 5 years BCE), and in astrology Kepler could not follow Roeslin's ideas and conclusions concerning comets and planetary motion.

Under the pen name "Lambert Floridus Plieninger," Roeslin published a paper concerning the calendar reform of Pope Gregory XIII. Like many other authors of his time (*e. g.*, **Wilhem IV** and **Michael Mäestlin**), Roeslin carried on the controversy against the new calendar, mainly for theological reasons, and claimed the pope wished to use the calendar to regain power over the Protestant church.

Jürgen Hamel
Translated by: *Peter Habison*

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Roger of Hereford

Flourished **England, 1176–1178**

Roger of Hereford was an astronomer working in the region of Hereford in the late 12th century. His alternative names perhaps reflect an English name "Young," "Lénfant," or "Childe."

Roger adapted the astronomical tables of Toledo for the meridian of Hereford in 1178, using as his basis the version composed for the meridian of Marseilles by **Raymond of Marseilles**. Two years earlier (1176) he wrote a work on the ecclesiastical *computus* (for calculating the church calendar), in which he compared unfavorably the traditional Latin learning on the *computus* with the new learning from Hebrew and Arabic sources.

Other writings attributed to Roger are several works concerning astrology, which may all derive from a *Liber de quattuor partibus iudiciorum astronomie*; this draws on the corresponding work of Raymond of Marseilles, as well as on translations of Arabic astrological texts made by **John of Seville** and Hermann of Carinthia. Roger may too have written on alchemy, if the *De rebus metallicis* once existing in Peterhouse, Cambridge, is authentic.

Roger was held in high esteem by contemporary English scholars, which is indicated by the fact that Alfred of Shareshill dedicated his translation of the Aristotelian text on botany, *De vegetabilibus*, to him. To Roger may be attributed the invention of a new way of calculating horoscopes mathematically. He did much to further the study of the mathematical sciences in England, and provides a link between the pioneers in this study, **Petrus Alfonsi** and **Adelard of Bath**, and **Robert Grosseteste**, who joined the bishop's household in Hereford while Roger was still active there.

Charles Burnett

Alternate names

Rogerus Infans
Rogerus Puer

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Rogerus Infans

➜ **Roger of Hereford**

Rogerus Puer

➜ **Roger of Hereford**

Rohault, Jacques

Born **Amiens, (Somme), France, 1620**
Died **Paris, France, 1665**

Jacques Rohault was a self-taught mathematician and experimentalist, and a popularizer of natural philosophy. He was the son of Ambroise Rohault and Antoinette de Ponthieu. In the mid-1650s, he began a series of extremely popular lectures on natural philosophy. These lectures popularized **René Descartes**'s natural philosophy, but laid great emphasis on experiment and observation, and omitted the metaphysical foundations that Descartes had gone to great trouble to provide. Rohault became the leading defender of Cartesianism in France, and his *Traité de physique* (Treatise on physics) (1671) became the leading textbook of the age. It offered a probabilistic reading of natural philosophy, but avoided any detailed mathematics, and completely ignored **Johannes Kepler**'s work. It presented natural philosophy as an observational discipline rather than a mathematical one. Nevertheless, the *Traité* was exceptional in the scope and clarity of its treatment. As far as cosmology is concerned, the keystone of Cartesian cosmology is the vortex theory, which explains the formation of stars and planets, and the stability of planetary orbits, in terms of the rotation of matter around central points, and Rohault offered a detailed defense of this theory, which was extended to gravity, magnetism, and other phenomena.

In 1697, Samuel Clarke brought out an English edition of the *Traité*, establishing it as the major natural philosophy textbook in England. Clarke's edition does nothing to challenge the vortex theory in its earlier versions, and makes no mention of gravitation, but in later editions the notes took on a strongly Newtonian flavor, so that the *Traité* became, in its later incarnations, a curious hybrid of Cartesianism and Newtonianism.

Stephen Gaukroger

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Römer [Roemer], Ole [Olaus]

Born **Aarhus, Denmark, 25 September 1644**
Died **Copenhagen, Denmark, 19 September 1710**

Ole Römer was a multifaceted Danish scientist and public servant, most noted for his discovery and determination of the finite velocity of light. He also constructed the first meridian transit circle incorporating a telescopic sight.

At the University of Copenhagen, Römer studied medicine under the brothers Thomas and **Erasmus Bartholin**. The latter was also a physical scientist who discovered the phenomenon of double refraction in crystals of Iceland spar, and tutored Römer in astronomy and mathematics.

In 1671, Römer's life was changed by the arrival of **Jean Picard**, who came to Denmark to determine the exact location of Uraniborg, **Tycho Brahe**'s old observatory. Römer assisted Picard in this task, during which they determined longitude by timing eclipses of Jupiter's satellite I (Io), after which they both traveled to Paris in 1672. There Louis XIV had established the most magnificent observatory in Europe, and appointed Römer as tutor to the dauphin.

During his 9 years in France, Römer turned his hand to a variety of tasks, as astronomers in those days were often general scientists and practical engineers. He devised improved instruments, such as clocks and micrometers, as well as supervising hydraulic works near Paris and in the provinces. What brought him fame, however, were his observations and interpretation of the times at which eclipses of Io occurred. This was a subject of important commercial and military importance at the time, for these phenomena offered the possibility of solving the intractable problem of determining one's longitude at sea. Because of the difficulty of making the necessary observations from the heaving deck of a ship, this method never fulfilled its promise.

Improvements in timing the beginnings of such eclipses, due to the improved accuracy and precision of contemporary clocks, had disclosed worrisome and unexplained problems in reconciling observations made at different times. These discrepancies might be explained if light had a finite velocity, but the prevailing opinion among scientists was that propagation was instantaneous.

In 1675, Römer predicted that the onset of an eclipse that was to begin on 9 November of that year would be 10 min later than otherwise expected, based on the speed of light being some 140,000 miles per second. This did indeed happen, and his estimate was not far off the modern determination of just over 186,000 miles per second. This demonstration was not universally accepted, and it was not until **James Bradley**'s 1729 discovery of the aberration of starlight, which demanded a finite velocity for light, that Römer was fully vindicated.

In 1679, Römer visited England where he met such contemporaries as **Isaac Newton**, **Edmond Halley**, and **John Flamsteed**. In 1681, he returned to Denmark at the request of Christian V, where he became in modern terms the royal scientific advisor, as well as director of the Copenhagen Observatory. Until his death, Römer held a bewildering variety of public positions, such as master of the Mint (similar to the position that Newton held), various appointments of a military and engineering nature, privy councilor, and even the effective mayor of Copenhagen.

In spite of these duties, Römer continued his scientific work, including building his own observatory, Tusculaneum, outside Copenhagen, designing new instruments for astronomical observations, and inventing a new type of thermometer, which later bore the name of Fahrenheit. During these last years, Römer also accumulated a vast store of astronomical observations, almost all of which perished in the 1728 Copenhagen fire. His first wife, Anna Maria Bartholin (daughter of Erasmus), whom he married in 1681, died in 1694; they had no children.

Much of what we know about Römer's astronomical work comes from **Peter Horrebow**'s 1735 book *Basis astronomiae sive astronomiae pars mechanica*.

Ronald A. Schorn

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Rooke, Lawrence

Born **Deptford, (London), England, 13 March 1622**
Died **Deptford, (London), England, 27 June 1662**

Lawrence Rooke held the astronomy chair at Gresham College in London and was a founding member of the group associated with the college that became the Royal Society of London soon after his death. He was educated at King's College, Cambridge (BA: 1643; MA: 1647). From 1650 to 1652, Rooke was a fellow of Wadham College, Oxford, before taking up the chair of astronomy at Gresham College in 1652. In 1657, he changed to the chair in geometry, which he held until his death. He was married and had four daughters and five sons.

Rooke was widely known as a learned, industrious scholar by contemporaries. Rooke's primary astronomical contributions are of observational, practical importance. His careful observations of cometary paths and his research on determining longitude at sea by observing lunar eclipses and the satellites of Jupiter exemplify Rooke's support for the "new philosophy" of science in 17th-century England. **Seth Ward** published Rooke's observations comet C/1652 R1. Essays on eclipses of the Moon and of the satellites of Jupiter appeared posthumously in the *Philosophical Transactions* of the Royal Society and in Thomas Sprat's *History of the Royal Society*.

Robinson M. Yost

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Rosenberg, Hans

Born **Berlin, Germany, 18 May 1879**
Died **Istanbul, Turkey, 26 July 1940**

German observational astronomer Hans Rosenberg made the first plot of stellar brightness versus spectral type, now called a Hertzsprung–Russell diagram, under the guidance of **Karl Schwarzchild**.

Rosenberg earned a Ph.D. from the University of Strasbourg for work under E. Becker on the variability of χ Cygni, a Mira-type variable. He received his *Habilitation* degree from Tübingen in 1910 for a thesis entitled "The relation between Brightness and Spectral Type in the Pleiades." This included a graph of apparent magnitude versus spectral class for the Pleiades, made at the suggestion of Schwarzschild, which was apparently the first of what we now call Hertzsprung–Russell diagram (for plots made by **Ejnar Hertzsprung** and **Henry Norris Russell** a few years later).

Rosenberg became head of the university observatory at Tübingen in 1912 and professor of astronomy there in 1916, in the midst of service in the German army (1914–1918). He was appointed professor of astronomy and director of the observatory at the University of Kiel in 1926, from which positions he was removed in 1935 under the *Reichsbürgergesetz* (roughly, laws pertaining to the citizens of the country) because he was Jewish. Fortunately, Rosenberg had taken a position as a guest lecturer at Yerkes Observatory (University of Chicago) in 1934 for a 3-year period. He went on to be professor of astronomy and director of the observatory in Istanbul, Turkey, from 1938 until his death.

Rosenberg was a pioneer of photoelectric photometry, applying the technique to comets, variable stars, and spectroscopic binaries. He led solar eclipse expeditions to Finland in 1927 and Thailand in 1929.

Christian Theis

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Rosenberger, Otto

Born **Tukkim, (Latvia), 10 August 1800**
Died **probably Halle, Germany, 23 January 1890**

Of German descent, Otto Rosenberger was assistant at Königsberg Observatory and later professor at Halle. He predicted the perihelion passage of Halley's comet (IP/Halley) in 1835 with great accuracy.

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Ross, Frank Elmore

Born **San Francisco, California, USA, 2 April 1874**
Died **Pasadena, California, USA, 21 September 1960**

Frank Ross is known for the Ross correcting lens and his lists of new proper-motion stars. His father, Daniel Ross, a building contractor, lost a fortune during the California gold-mining boom. In 1882, the family moved to San Rafael, California, where Ross attended grammar school and cultivated an interest in mathematics. He entered the University of California at Berkeley and received his BS degree in 1896. He got his Ph.D. from the same institution in 1901.

Ross was appointed as an assistant at the Nautical Almanac Office, Washington, District of Columbia (1902), research assistant in the Carnegie Institution (1903–1905), and director of the International Latitude Station at Gaithersburg, Maryland (1905–1915). He joined the Eastman Kodak Company (1915), and carried out important investigations on the physics of the photographic process until 1924 when he joined the Yerkes Observatory of the University of Chicago as Associate Professor. Promoted to professor in 1928, Ross retired to Pasadena, California, in 1939.

To increase the size of the usable field of large reflectors, Ross invented a correcting lens system still in use. At the telescope himself, he discovered many stars with large proper motions and numerous variable stars. Ross also built upon **William Wright**'s pioneering work at the Lick Observatory by photographing Mars in the light of five different colors, during the opposition of 1926.

In 1927, Ross imaged Venus in the ultraviolet with the 60- and 100-in. reflectors of the Mount Wilson Observatory in order to register dusky markings that he interpreted as atmospheric disturbances. No detail was visible in the red and infrared, and he concluded the upper atmosphere of Venus is composed of thin cirrus-like cloud, while the lower part is exceedingly dense and yellowish. Thirty years elapsed before astronomers finally took note of this important revelation and understood what it signified.

Ross photographed large-scale structures not previously recognized in the Milky Way. This study culminated in 1934 with the publication of the *Atlas of the Northern Milky Way* with Mary Calvert, **Edward Barnard**'s niece, and Kenneth Newman.

Richard Baum

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Rossi, Bruno Benedetto

Born **Venice, Italy, 13 April 1905**
Died **Cambridge, Massachusetts, USA, 21 November 1993**

Italian–American cosmic-ray and X-ray physicist Bruno Rossi is honored within astrophysics as the guiding spirit of the first rocket-borne detectors intended to look for X-ray sources outside the Solar System. The first of these, flown in 1962, saw one strong source and the X-ray background, and opened a whole new window on the cosmos.

Bruno Rossi, the son of Rino Rossi and Lina Minerbi, received his BA degree from the University of Padua and his Ph.D. from the University of Bologna in 1927. On completion of his university studies, Rossi was appointed assistant to Antonio Garbasso at the University of Florence in 1928. There his lifelong interest in the nature and origins of cosmic radiations was inspired by a paper of Walther Bothe and **Werner Kolhörster** describing their discovery of charged cosmic-ray particles that penetrated 4.1 cm of gold. They concluded that most of the local cosmic rays are not gamma rays as was generally believed at the time, but energetic charged particles.

Within a few weeks of reading the paper, Rossi invented an electronic coincidence circuit with which nearly simultaneous pulses from two or more Geiger counters could be recorded with a time resolution better than 1 millisecond. It was the first electronic AND circuit, a basic logic element of future electronic computers. Its applications by Rossi in a series of pioneering experiments carried out in the period from 1930 to 1933 marked the effective beginning of electronic methods in nuclear and particle physics. Rossi demonstrated the presence in cosmic rays of penetrating charged particles, now called muons, capable of traversing more than 1 m of lead. He identified the "soft" component that interacts in thin layers of lead to produce secondary showers of particles. In an experiment carried out in Eritrea, Rossi measured the east–west asymmetry in the intensity of cosmic rays that he had predicted in 1930 in a theoretical analysis of the deflection of charged particles by the Earth's magnetic field. The direction of the asymmetry proved that the charges of the primary particles are predominantly positive. In the course of the same experiment, Rossi discovered the nearly simultaneous arrival at ground level of many particles generated by a single primary of very high energy, the phenomenon now called extensive air showers.

In 1932, Rossi was called to the University of Padua to establish a new physics institute. He married Nora Lombroso in April of 1938. In September of the same year, he was dismissed from his university position in accordance with the racial laws of the facist state. Recognizing the looming danger, the Rossis left Italy. After brief visits to the Bohr Institute in Copenhagen, Denmark, and the laboratory of **Patrick Blackett** at the University of Manchester, England, they traveled on to Chicago, Illinois, USA, where **Arthur Compton** had invited Rossi to participate in a cosmic-ray symposium at the University of Chicago during the summer of 1939.

The muon and its possible instability were major topics at the symposium. Afterward, in Compton's laboratory, Rossi constructed an apparatus with which he carried out the first of a series of experiments on Mount Evans in Colorado and at Cornell University, Ithaca, New York, that proved the radioactive decay of muons, demonstrated the relativistic dilation of the mean life of rapidly moving muons, and ultimately determined the precise value of the mean life of muons at rest. The latter was achieved at Cornell University, where he was appointed associate professor in 1940.

In 1943 Rossi was called to Los Alamos, New Mexico, to participate in the development of the atomic bomb. There he headed the group that developed the special electronic instrumentation required for the urgent experiments in nuclear physics. Among the new instruments were fast ionization chambers that Rossi used in the dangerous implosion experiments and, ultimately, in measuring the exponential rise of the chain reaction of the plutonium bomb detonated on 16 July 1945 at Alamogordo.

In 1946 Rossi was appointed professor of physics at the Massachusetts Institute of Technology [MIT]. Here, he formed the Cosmic Ray Group with several of his young colleagues from Los Alamos, other scientists returning to academic work from wartime laboratories, visitors from Asia and Europe, and numerous students. From 1946 to 1960, various members of the group, inspired and guided by Rossi, carried out a wide variety of studies on the properties of the primary cosmic rays, on the propagation of the primary and secondary cosmic rays in the atmosphere, and on new unstable particles produced in the interactions of cosmic rays with matter. Among the studies with special significance in the developing field of high-energy astronomy were a series of experiments on extensive air showers that determined the arrival directions and energy spectrum of the primary cosmic rays with energies in the range up to 10^{20} electron volts.

In the late 1950s, Rossi seized new opportunities for cosmic exploration offered by the advent of space vehicles and computers. His group developed the MIT "plasma cup" for measuring the properties of ionized gas in interplanetary space. Together with a magnetometer prepared at the Goddard Space Flight Center, it was launched aboard the space probe Explorer 10 on 25 March 1961. The measurements revealed the boundary of the geomagnetic cavity and determined the density, supersonic speed, and direction of the solar plasma flowing just outside the cavity. Ever more sophisticated plasma detectors developed by the MIT group were sent in the following years around the planets and the boundary of the Solar System.

Rossi was also eager to explore the sky for possible X-ray sources with detectors carried above the atmosphere. At Rossi's suggestion, an effort to accomplish that purpose was undertaken at American Science and Engineering, Inc., a local company, which was founded in 1958 by a former student of Rossi, and for which Rossi was cheif scientific consultant. With support from the United States Air Force, an experiment, developed under the direction of Riccardo Giacconi, was launched on 18 June 1962. It discovered the first X-ray star, Sco X-1, and an unresolved X-ray background, thereby inaugurating the field of extrasolar X-ray astronomy.

In his later years, Rossi wrote and spoke extensively about space physics and X-ray astronomy, and published his scientific autobiography. He received honorary doctorates from the universities of Palermo, Durham, and Chicago and prizes from Italy, the United States, Bolivia, Germany, and Israel (the Wolf Prize). He was elected to the major academies of science in Italy, England, and the United States and is remembered by the Rossi Prize in High Energy Astrophysics of the American Astronomical Society.

George W. Clark

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Rossiter, Richard Alfred

Born **Oswego, New York, USA, 19 December 1886**
Died **Bloemfontein, South Africa, 26 January 1977**

Sharp eyesight allowed Richard Rossiter to discover the largest number of double stars observed by anyone up to his time, while his dedication kept his observatory functional during tough economic times.

Rossiter earned his B.A. degree at Wesleyan University in 1914, his M.A. from the University of Michigan in 1920, and his Ph.D. from the University of Michigan in 1923. He had married Jane van Dusen in 1915. The Rossiters had two children, Laura Rossiter (Kohlberg) and Alfred Rossiter.

After graduating from Wesleyan, Rossiter taught mathematics at the Wesleyan Seminary at Genesee, New York, until 1919. Upon completion of his doctorate, Rossiter remained at Michigan as an assistant professor of astronomy. In 1926, Rossiter left Michigan for South Africa, where he was appointed director of the Lamont–Hussey Observatory in Bloemfontein until his retirement in 1952. He was a member of the Astronomical Society of Southern Africa and served as its president in 1940.

Rossiter's doctoral dissertation, directed by **Ralph Curtiss**, was an intensive study of the eclipsing binary star, β Lyrae. Rossiter amassed over 400 spectrograms of the star during his research. He measured shifts in opposite directions of the brighter spectral lines and proved from these observations that the star was rotating rapidly. While **Frank Schlesinger** had provided evidence for suspected stellar rotations before this time, Rossiter's observations, along with those of **Dean McLaughlin** for Algol, offered the first convincing proof for what is now known as the Rossiter–McLaughlin rotation effect. In recent years, the effect has been used to deduce the existence of planets orbiting some stars.

William Hussey, head of Michigan's astronomy department, had long intended to establish a southern station in order to prosecute his survey of double or binary stars, begun at the Lick Observatory under director **Robert Aitken**. Hussey's friend Robert P. Lamont, by then a wealthy industrialist, offered to finance such an expedition. By the mid-1920s, the MacDowell firm had completed a 27-in. refractor for that purpose. Hussey began examining observing sites in the neighborhood of Bloemfontein. He sought out Rossiter to take part in the expedition, originally planned to take just a few years. But in October 1926, while *en route* to South Africa, Hussey died in London, and Rossiter took over the research agenda.

Once in Bloemfontein, Rossiter chose an excellent site, set up the observatory, and, with two younger colleagues, began the double-star survey. Morris K. Jessup returned to the United States in 1930 and Henry F. Donner followed 3 years later, although Donner returned for a single season in 1948. The number of double stars discovered at the Lamont–Hussey Observatory (7,368) is a record. Rossiter's personal harvest of new pairs (5,534) is itself a world record.

During the Depression, Lamont ceased to fund the observatory and Rossiter obtained local funds during the 7 years that Michigan could not support the program. Rossiter became a staunch member of the Bloemfontein community and never returned to the United

States. He also hosted **Earl Slipher** of the Lowell Observatory during two close oppositions of Mars. There, Slipher used a special camera to take an excellent series of photographs of the red planet. During the 1950s, Karl Henize used the site for important work on emission nebulae, while Frank Holden continued the double-star survey work.

Records of the Lamont–Hussey Observatory, including correspondence from Rossiter, are found in the Michigan Historical Collections, Bentley Library, University of Michigan.

Rudi Paul Lindner

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Rothmann, Christoph

Born **Bernburg, (Sachsen-Anhalt, Germany),** ***circa*** **1560**
Died **possibly in Bernburg, (Sachsen-Anhalt, Germany),** ***circa*** **1600**

Christoph Rothmann constructed the first modern star catalog based entirely on his own observations.

He was one of the most outstanding astronomers of the 16th century, but we have scant information on Rothmann's life. His enrollment at the University of Wittenberg on 1 August 1575 is authenticated. There is no reliable information about the course of his studies or which academic degree he received.

According to all we know, Rothmann concerned himself thoroughly with mathematics and astronomy in Wittenberg. He expressed that to **Tycho Brahe** as well as in his extant manuscript works. In November 1584 he started to work with Landgrave **Wilhelm IV** of Hessen-Kassel as an astronomer at the local observatory. (Dates usually referred to in the literature turn out to be wrong.) Rothmann stayed in Kassel until mid-1590. In the summer of that year he went on a journey to Brahe, studied his instruments, and left Brahe's island on September 1. His further life is still a mystery. In spite of all commitments and arrangements with the count, Rothmann never returned to Kassel, but took up residence in Bernburg, where he later wrote a treatise on the sacraments, in particular on the sacrament of baptism.

In connection with his work on the star catalog initiated by Wilhelm IV, Rothmann became an excellent observer. Rothmann's catalog elaborated for the epoch of 1586 shows an extremely small standard deviation (related to the fundamental star Aldebaran) of ± 1.2′ in right ascension and ±1.5′ in declination. (For comparison, Brahe's respective values are: ±2.3′ for right ascension and ±2.4′ for declination.)

The Kassel stellar catalog comprises 383 stars; the corresponding observations date from the years 1585–1587. It represents a decisive breakthrough in modern astronomical observation, and it was the first one since the time of **Hipparchus** and **Ptolemy** to be completely based on observations by the compiler. Rothmann did not work with instruments of large dimensions, but used smaller metal instruments (*e. g.*, an azimuthal quadrant) with particular precisely manufactured sighting devices as well as precise clocks constructed by **Jost Bürgi**. Furthermore, he paid great attention to a precise calibration of the instruments, considered refraction to correct his observational results, and carried out numerous single measurements for each stellar location. The Kassel star catalog was included as an exemplary one by **John Flamsteed** in his *Historia coelestis Britannicae volumen tertium*.

After observing the comet of 1585 (C/1585 T1), Rothmann was one of the first astronomers to conclude that comets are cosmic objects. Rothmann had observed the comet from 8 October to 8 November, did not find a parallax, and determined the distance between the comet and the Earth to be 500,000 German miles; therefore it must have been far beyond the sphere of the Moon. In connection with previous observations by Brahe and other scholars, he followed the anti-Aristotelian conclusion that the comet's substance is by no means different from the elemental region below the Moon, and that therefore the doctrines of the ether as well as that of a particular celestial region of fire are completely unfounded from a scientific point of view. Rothmann considered comets as vapors (fumes) arising from the Earth, which shone in sunlight; this appears as a conservative element at first glance, but it led him to the insight of the material unity of the Earth with the comets as celestial bodies and therefore of the material unity of the whole cosmos up to the planetary spheres.

Peter Apian had observed that comet tails are always turned away from the Sun. Rothmann seems to have noticed this common fact, and used it to clarify the nature of comet tails. As he discovered from his own observations and those by Wilhelm IV of the comet of 1558 (C/1558 P1), comet tails are directed exactly neither to the Sun nor to the planets. Therefore, they must represent an independent body of specific matter by themselves.

Rothmann's unorthodox comet doctrine shows him as an independent thinker who tried to get to conclusions from his own observations and reflections. But it is always evident that for Rothmann, precise observations were the starting point and the basis for theoretical conclusions. This applies also to his investigation of refraction. Rothmann had noticed differences in star distances depending on their height over the horizon, and united it in a table. (Brahe did the same simultaneously, and Rothmann conducted long written discussions with him about that.) He concluded from the specific progression of the refraction and of the equality of refraction for planets and fixed stars that there are neither rigid spheres for the movement of the planets nor a separate sphere of fire or a crystal sky. Therefore, there is nothing else than air and the planets moving in it between the sphere of the fixed stars and the Earth. Hence, refraction has no other cause than a diversion of light at the transition from the air of the sky to the air close to the body of the Earth, being mixed with earthly vapors up to a height of approximately 102 kilometers. Contrary to that, Brahe clung to the opinion that refraction originates at the transition of light from the celestial ether to the atmosphere of the Earth. In this case, Rothmann argued, refraction had to continue until the zenith, which neither he nor Brahe had ever measured. So Rothmann gave up a general division into two world regions below and above the Moon.

Because at this point Rothmann had already given up essential elements of Aristotelian physics, he was able to take the last step in accepting the heliocentric system of **Nicolaus Copernicus** as the true construction of the world. In Kassel he became one of the first convinced disciples of the heliocentric system, as is documented in numerous places in his letters to Brahe and in his treatise on the comet of 1585.

Rothmann's correspondence with Wilhelm IV is in the Hessian State Archive, Marburg. Rothmann's works, as original manuscripts, are in the Murhard University and University Library in Kassel.

Jürgen Hamel and *Eckehard Rothenberg*
Translated by: *Günther Görz*

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Rowland, Henry Augustus

Born **Honesdale, Pennsylvania, USA, 27 November 1848**
Died **Baltimore, Maryland, USA, 16 April 1901**

Henry Rowland is chiefly remembered for his invention and manufacture of the concave diffraction grating, the extraordinary precision that it brought to the science of solar astrophysics, and his *Photographic Map of the Normal Solar Spectrum* (1888). Rowland was the son of Henry Augustus Rowland, Sr., a Presbyterian clergyman, and Harriette Heyer. In the spring of 1865, he enrolled at the Phillips Academy in Andover, Massachusetts, to study Latin and Greek, with the intention of preparing for the ministry. But in the fall of that year, Rowland transferred to the Rensselaer Polytechnic Institute in Troy, New York, from which he graduated in 1870 with a degree in civil engineering. After employment as a railroad surveyor for a year and as a teacher at the College of Wooster in Ohio, he returned to Rensselaer as an instructor of physics and became an assistant professor 2 years later. His demonstration that the magnetic permeability of iron, steel, and nickel varied with the applied magnetizing force convinced **James Maxwell** that Rowland was a promising experimentalist.

In 1875, Daniel Coit Gilman, founding president of the Johns Hopkins University, Baltimore, appointed Rowland as the institution's first professor of physics. Rowland held this chair until his premature death. In that capacity, he advised 165 graduate students, including 45 doctoral students, 30 of whom find mention in James McKeen Cattell's *American Men of Science*. Rowland was instrumental in establishing physics as a research discipline in America.

In 1890, Rowland married Henrietta Troup Harrison; the couple later had three children. In the same year, however, Rowland learned that he had diabetes, which was then untreatable. The more commercially oriented activities he conducted toward the end of his life, such as developing and marketing a multiplex telegraph, his role as chief design consultant to a construction company for installing electric generators at Niagara Falls, and his filing of at least 19 patent applications, were aimed at assuring a future livelihood for his family. At his own request, Rowland's cremated ashes were masoned into the wall of his laboratory close to the ruling engine he had devised.

While working in the Berlin laboratory of **Hermann von Helmholtz**, Rowland demonstrated for the first time that moving charges on a rotating disk create magnetic effects resembling those from an electric current. He purchased scientific instruments in Europe totaling more than $6,000 to equip his Baltimore laboratory and its associated workshop. Rowland's lab at Johns Hopkins became the best equipped of his generation in the United States and attracted many research students. His early work included precision measurements of the value of the unit of electrical resistance, the ohm, and his determination of the mechanical equivalent of heat, for which he was awarded the Rumford Medal in 1884.

In the early 1880s, Rowland improved the design of the "ruling engine," which guided a carefully chosen, sharp, diamond point across a speculum metal surface to produce parallel ruled lines at a fixed separation of as little as one thousandth of a millimeter. The straightness of the lines was achieved by guiding the point along two parallel rails of hardened metal. More difficult was the point's repositioning after each ruling for up to 110,000 lines in a single grating. Rowland's success lay in his using a well-machined ruling screw made of special flawless steel in a painstaking grinding process that could take up to 14 days without interruption. Rowland once claimed that "there was not an error of half a wave-length, although the screw was nine inches long."

Rowland's gratings were much larger and more regular than any constructed by his American predecessors, **Lewis Rutherfurd** and William August Rogers, and were free of the periodic errors that caused the appearance of pseudo-lines (termed ghosts) in the diffraction spectra of other gratings. Throughout his career, Rowland built three such ruling engines, the first in 1881, which could rule up to 14,400 lines per inch. Afterward, he constructed two others (in 1889 and 1894) that ruled 20,000 and 15,000 lines per inch, onto surfaces up to 25 square inches.

In 1882, Rowland devised the concave diffraction grating. With a radius of curvature between 3 and 6 m, the ruled metal surface acted not only as a diffraction grating, but also as a focusing lens, thus obviating the use of glass lenses with their unwanted light absorption from the ultraviolet spectrum. During the late 19th and early 20th centuries, all major spectroscopists acquired at least one of Rowland's gratings. They allowed spectral work to be performed on a broader range of frequencies and with much higher efficiency and precision (by roughly a factor of 10) as compared with other gratings. They were manufactured in Baltimore by Rowland's chief mechanician, Theodore Schneider, and passed a rigorous examination by his assistant, Lewis E. Jewell. Rowland's distributor, the Pittsburgh instrument maker **John Brashear**, also supplied the polished curved surfaces. By January 1901, sales from the gratings totaled more than $13,000; between 250 and 300 gratings were sold at cost to physical and chemical laboratories as well as to astronomical observatories the world over.

While many of his students recorded the wavelengths of various emission spectra, Rowland and Jewell concentrated on photographic mapping of the entire visible solar spectrum at an unprecedented resolution. Rowland's tabular inventory of roughly 20,000 solar spectral lines was published in the *Astrophysical Journal* (1895–1897), and his spectral-atlas was distributed in two series of large-scale prints. Every noteworthy spectroscopic laboratory and many astronomical observatories obtained these publications, which formed the standard of solar spectroscopy for several decades.

Rowland's tables provided the basis on which the Balmer (and other) wavelength series were derived. The precision of his instruments also permitted detection of the Zeeman effect and proof of the magnetic polarities of sunspots and related solar phenomena discovered by **George Hale** in 1908. Around 1890, the first indications of a solar redshift were discovered in these data by Jewell, who attempted to interpret them as Doppler effects induced by solar convection currents. Rowland himself dismissed the effect as some type of artifact. It was not until around 1960 that interpretation of this effect as a gravitational redshift (predicted by **Albert Einstein** in 1907) was finally confirmed.

Rowland was a founding member and first president of the American Physical Society. In recognition of his importance in the institutionalization of American physics, he was awarded LL.D. degrees from Yale University in 1895 and from Princeton University in 1896. His diffraction gratings and photographic maps of the solar spectrum won him the Gold Medal of the French Académie des sciences and a grand prize at the Paris Exhibition of 1890, along with the Draper Medal of the National Academy of Sciences. Rowland served as a delegate for the United States at various international scientific congresses. He was elected a foreign member of the Royal Society of London and about a dozen other learned societies and academies.

Rowland's papers are preserved at the Milton S. Eisenhower Library, Johns Hopkins University, Baltimore.

Klaus Hentschel

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Roy, Hendrick de

➔ **Regius, Hendrick**

Rudānī: Abū ˁAbdallāh Muḥammad ibn Sulaymān (Muḥammad) al-Fāsī ibn Ṭāhir al-Rudānī al-Sūsī al-Mālikī [al-Maghribī]

Born **Tārūdānt, (Morocco), *circa* 1627**
Died **Damascus, (Syria), 1683**

Rudānī, also known as *al-Maghribī*, was a 17th-century scholar who lived in the Ottoman territories and was known for his work on astronomical instruments. In addition to astronomy, he was a poet and also wrote on mathematics, *hadith* (traditions of the Prophet), Qur'ān interpretation, and grammar. There is no information about Rudānī's elementary education or about his family background. He received his education in the *madrasa*s (schools) of Morocco and Algeria. Then he traveled to the east, visiting Egypt, Damascus, and Istanbul and receiving education from eminent scholars along the way. Eventually, Rudānī moved to the Ḥijāz in Arabia, where he became one of the most respected scholars in the area, and was appointed governor. But due to a conflict, he was exiled to Damascus.

In the field of astronomy, Rudānī wrote works on instruments, timekeeping, and the *qibla* (direction to Mecca). He sought practical solutions and ways to simplify the calculations. With these purposes in mind, Rudānī invented a sphere, called *al-jayb al-jāmiˁa*, which was a spherical device in which another sphere (painted blue) with a different axis was attached to it. This second sphere was divided into two parts in which the zodiacal signs with their sections and regions were drawn. The purpose of this device was to facilitate timekeeping with the use of this one instrument. The device, easily constructed, was a universal instrument (*i. e.*, it could be used for different longitudes and latitudes). Unfortunately, there is no existing sample of this device, but Rudānī wrote a book describing it, in Arabic, entitled *al-Nāfiˁa fī ˁamal al-jāmiˁa*. It was written in Medina in 1662 and contains 45 parts and a conclusion. Rudānī's best-known work in the field of astronomy is *Bahja al-ṭullāb fī al-ˁamal bi-'l-asṭurlāb*, a book written in Arabic on how to make and use an astrolabe. There are 13 extant copies of this particular work. Interestingly, Rudānī also wrote three other works on the same subject. Other astronomical works by Rudānī include one on prayer times and another on the calendar in rhyme.

Salim Ayduz

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Rümker, Christian Karl Ludwig

Born **Stargard, (Mecklenburg-Vorpommern, Germany), 18 May 1788**
Died **Lisbon, Portugal, 21 December 1862**

In 1822 Karl Rümker made the second ever successful recovery of a periodic comet (2P/Encke).

The son of Justus Friedrich Rümker, Court-Councillor of the duchy, young Karl was educated at the Grey convent in Berlin. With a talent for mathematics, Rümker was then sent to the Builders' Academy in Berlin because his family hoped he would become a master-builder. Instead, he moved to Hamburg in 1807 where he taught mathematics privately. Napoleon's continental blockade made the economic situation increasingly difficult, and around 1809, Rümker traveled to England in search of maritime employment. He served for several years in the merchant navy but in July 1813 was press-ganged for service on the man-of-war, *HMS Benbow*. What for many would have been a misfortune proved a stroke of luck for Rümker. The captain of the *Benbow* learned that he was no ordinary seaman but a teacher of mathematics. Rümker then served on a succession of naval vessels as a "teacher of sea cadets" with an officer's rank.

Rümker's naval service took him to the Mediterranean where he met the Austrian astronomer **János von Zach**, editor of the *Correspondence Astronomique*. Zach encouraged Rümker's astronomical skills and published his first scientific observations. Publication of Rümker's observations at Malta in the *Edinburgh Philosophical Journal* (1819) brought his name to wider scientific attention. He was discharged from the navy in that year and returned to Hamburg, where he taught at the School of Navigation.

The appointment of Sir **Thomas Brisbane** as the prospective governor of the British colony of New South Wales (Australia) saw Rümker abandon his Hamburg post and return to England in 1821. Brisbane had sought the appointment in part so that he could establish a Southern Hemisphere observatory. Rümker learned of Brisbane's desire for an astronomical assistant, applied for the position, and was accepted. Rümker's salary was to be £200.

Brisbane's party, including Rümker and a second assistant, James Dunlop, arrived in Sydney toward the end of 1821. The modest observatory Brisbane erected near Government House at Parramatta was completed in April 1822; observations began almost immediately. The main task of the observatory was to determine accurate positions of stars located between the zenith and the South Celestial Pole. Rümker served as principal astronomer, the relatively unskilled Dunlop as his assistant, and Brisbane participated as his duties allowed. Rümker and Dunlop observed comet 2P/Encke on 2 June 1822. This was only the second occasion on which the predicted return of a comet had been fulfilled. Brisbane praised Rümker's "zeal, assiduity [and] intelligence" for the discovery.

Nonetheless, strains developed between the punctilious astronomer and the private patron. In June 1823, Rümker suddenly left Parramatta to farm the land he had previously been granted at Picton, to the southwest of Sydney. Rümker devoted himself to the development of Stargard, as he called the property, and proved himself an able farmer. After a year, he resumed astronomical observations with a small telescope, discovering three comets in 1824/1825. Brisbane's attempts at reconciliation were rebuffed, and it was not until after he departed from the colony (1825) that Rümker was reinstated at Parramatta. The local government purchased Brisbane's instruments and books so that the observatory could be operated once again.

Rümker resumed work at Parramatta (but without Dunlop's assistance) in 1826, now as a government servant. The new governor, Sir Ralph Darling, suggested to authorities in London that Rümker be made "Government Astronomer." Without receiving official confirmation, Darling appointed Rümker to this position at a salary of £300. No small part of Darling's motivation for the renewed patronage was the prospect of measuring an arc of the meridian, as urged by the Royal Society of London. Rümker, however, felt this could not be achieved with the instruments at hand and returned to London to expedite the procurement of suitable equipment and to see through the publication of his observations.

Rümker arrived in London toward the middle of 1829. At first all went well; his Parramatta observations were to be published by the Royal Society (at government expense) at the end of that year. But then he was caught up in the dispute between the president of the Royal Astronomical Society, Sir **James South**, and the Royal Society itself. South had offered his Troughton transit circle for Parramatta, but when he sought to profit on its sale, a less expensive one was procured from Thomas Jones. Compounding this snub to South were the past grievances of Brisbane aired toward Rümker. Brisbane sought control of the Parramatta observation books from Rümker, whom he thought was withholding them. As a result of this vitriolic campaign against him, Rümker was formally dismissed from government service on 18 June 1830. Dunlop returned to Parramatta.

Rümker returned to Hamburg and was appointed director of the School of Navigation where he had previously taught. While there, Rümker published a *Preliminary Catalogue of Fixed Stars* (1832) from his Parramatta observations and dedicated the work to Brisbane. In 1832, he had an illegitimate son, George Friedrich Wilhelm Rümker, with his housekeeper, Maria Louise Bernadine Melcher, whom he did not marry. Years later (1848), Rümker married an astronomically minded English spinster, Mary Ann Crockford, who had reportedly independently discovered comet C/1847 T1 (Mitchell).

In 1833, Rümker was appointed director of Hamburg Observatory, in addition to his Navigation School position. An assiduous dedication to his tasks is reflected in the numerous papers he contributed to various scientific journals, along with his publication of a *Handbuch der Schiffarts-Kunde* (Manual of the theory of navigation). He was elected to memberships in both the Royal Society and the Royal Astronomical Society in London. In 1850, the King of Hanover presented Rümker with a Gold Medal for Arts and Science. Four years later, he was awarded the Gold Medal of the Royal Astronomical Society.

Yet, this heavy load took its toll on Rümker's health. Too ill to travel to London to receive his 1854 medal, Rümker was permanently crippled by a severe fall in 1857. He resigned from his posts but was given an indefinite leave of absence. His son George succeeded him as director of the Hamburg Observatory. Hoping to relieve a chronic lung complaint, Rümker traveled with his wife to the warmer climate of Southern Portugal where he died. He was buried in the English Cemetery at Estrella.

Besides the recovery of comet 2P/1822 L1 (Encke) and the publications already mentioned, Rümker's work contributed substantially to *A Catalogue of 7385 Stars, Chiefly in the Southern Hemisphere: Prepared from Observations Made in the Years 1822, 1823, 1824, 1825, and 1826, at the Observatory at Paramatta, New South Wales*, prepared by William Richardson and published in 1835. Toward the end of his life, Rümker was again reducing his Parramatta observations but did not live to complete the task. These observations were eventually reduced and published by **Friedrich Ristenpart** (1909) and J. E. Baron de Vos van Steenwijk (1923). Rümker's manuscripts appear to have been destroyed in World War II.

Rümker made significant contributions to Southern Hemisphere astronomy in the years before the Cape Town Observatory was operational. His career illustrates the difficulties of professional scientists emerging from a context dominated by amateurs and the perils of patronage.

Julian Holland

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Rumovsky, Stepan Yakovlevich

Born **Stary Pogost (near Vladimir), Russia, 29 October/9 November 1734**
Died **Saint Petersburg, Russia, 6/18 July 1812**

Stepan Rumovsky was a Russian astronomer, mathematician, geodesist, and humanist scholar, who determined the most accurate value of the solar parallax during the 18th century. One of the best students at the Alexander Nevsky seminary, Rumovsky was chosen in 1748 to study at the university of the Saint Petersburg Academy of Science. There, he attended lectures by **Mikhail Lomonosov**, Georg Wilhelm Richmann, and other prominent Russian academicians.

Having majored in mathematics, Rumovsky became an adjunct of the academy in 1753 and was sent to Berlin to continue his mathematical training under **Leonhard Euler**.

After returning to Saint Petersburg, Rumovsky taught mathematics and astronomy at the university (1756–1812) and held various positions at the Saint Petersburg Academy – director of the geographical department (1766–1786), after Lomonosov's death; director of the academy's astronomical observatory and professor of astronomy (1763–1812); full member of the academy (1767); and academy vice president (1800–1803). He was also elected an honorary member of the Swedish Academy of Sciences (1763).

In 1761, Rumovsky took part in an expedition to Selenginsk (near Lake Baikal) to observe the transit of Venus. In 1769, he supervised a more comprehensive project to observe that century's final transit from several locations. Rumovsky himself observed it from the Kola Peninsula. Using data from all such observations conducted in 1761 and 1769, he calculated the value of the solar parallax at 8.67 arc-seconds, which was closer to its presently accepted value (8.79 arc-seconds,) than that derived by any of his contemporaries.

In 1762, Rumovsky compiled and published the first catalog of astronomically determined geographic coordinates for 62 sites in Russia. His determinations were remarkably precise (as noted by **Friedrich Struve** and others) and were incorporated into the 1790 edition of the *Berliner Astronomisches Jahrbuch*.

Rumovsky's more than 50 scientific works cover astronomy, geodesy, mathematics, and physics. He knew several modern languages as well as Latin, and translated literary and scientific works of Cornelius Tacitus, **Georges Leclerc**, and Euler into Russian.

In 1803, Rumovsky became a member of the Russian School Administration Board, which was charged with preparing educational reforms, and also superintendent of the Kazan department of education. In this capacity, he put much effort into the founding of the Kazan University. Rumovsky recruited, among others, Austrian astronomer **Johann von Littrow** and the German mathematician Johann Martin Bartels, who later became a teacher of **Nikolai Lobachevsky**.

Yuri Balashov

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Runge, Carl [Carle] David Tolme

Born **Bremen, (Germany), 30 August 1856**
Died **Göttingen, Germany, 3 January 1927**

Mathematician and physicist Carl Runge is most likely to be recognized by modern astronomers for the Runge–Kutta method of integrating complex differential equations numerically, which is of importance in calculating stellar structure and evolution. His most extensive contributions were, however, in laboratory and astrophysical spectroscopy.

Runge was the third son of Julius Runge and his wife Fanny Runge (*née* Tolme). The first years of his life were spent in Havana, Cuba, where his father, a successful merchant, was Danish consul. After the family's return to Bremen, where his father died unexpectedly, Carl attended the Lyceum and entered the University of Munich, in 1876, to pursue literature and philosophy. Soon, however, he turned to mathematics and left the following year for the University of Berlin where he studied with Karl Weierstrass and Leopold Kronecker and received his doctorate in mathematics in 1880. Runge was appointed a lecturer in mathematics at the University of Berlin 3 years later. During this time he worked on problems in algebra and number theory. Runge caught the attention of physiologist Emil du Bois-Reymond's family and married their daughter Aimée in 1887. They had six children, two sons and four daughters, one of whom, Iris, would be his biographer. A year prior to the marriage, Runge's father-in-law-to-be had helped him to obtain a professorship at the Technical High School of Hanover, a position he would hold for 18 years.

By a year after his arrival at Hannover, Runge had undergone a complete reorientation in his research interests, which now included mathematics, spectroscopy, astrophysics, and geodesy. His most important contributions are probably those in applied mathematics. With M. W. Kutta, Runge's name is associated with the Runge–Kutta methods to integrate differential equations numerically.

In a publication of 1885, **Johann Balmer** presented a formula that well represented the visible series of lines in the spectrum of hydrogen. Runge decided to find a comparable formula giving the spectral lines for each of the elements. He began his studies using published data for the spectra of lithium, potassium, calcium, and zinc. Runge found a number of formulae, but inaccuracies in the data made the results suspect. He discussed the matter with his colleague spectroscopist Heinreich Kayser, who agreed to help. In the interim, Rowland gratings and photographic techniques had become available so that more accurate measures of wavelengths could be made. For the next 7 years, until Kayser was appointed to the University of Bonn, they worked together. Runge calculated the series and helped with the experimental work.

Essentially, Runge had found that spectral series could be represented by adding an additional term to Balmer's formula. As the work progressed, emphasis was placed on the precision of the data, methods of data reduction, and evaluation of constants. Meanwhile, the Swedish physicist **Johann Rydberg** had worked out an empirical equation from which he was able to deduce Balmer's relation. Rydberg's formula connected directly with the theory of atomic structure formulated by **Niels Bohr** in which Runge took enthusiastic interest. Theoretical justification for spectral series of more complex atoms than hydrogen had, however, to await the development of quantum mechanics in the 1920s and 1930s. The precise data of Kayser and Runge were valuable in testing these more elaborate pictures of atomic structure.

After Kayser left, Runge continued on alone for 6 months until, following William Ramsay's discovery of terrestrial helium, Runge persuaded Friedrich Paschen (who had come to Hanover in 1891 as Kayser's teaching assistant and who had yet to discover the series of hydrogen lines bearing his name) to join him in an investigation of the helium spectrum. Shortly thereafter, they identified all of helium's principal lines and were able to arrange them into not one but two series. This was taken to mean that helium was a mixture of two elements until in 1897 the two scientists showed that oxygen also had more than one system or series.

By 1900, Runge and Paschen had turned to an investigation of the Zeeman effect – the splitting of spectral lines in a magnetic field. Together, they established the main Zeeman types and the series character of several groups of spark-spectra lines of the alkali earth elements.

In his spectroscopy, Runge was always on the lookout for astrophysical applications. New spectra were compared with **Henry Rowland**'s solar spectrum obtained with a finely ruled grating. Runge doubted the discovery of helium in the Sun by **Norman Lockyer**, until a particular yellow line was seen to be double, like the one produced by terrestrial helium. His work with Kayser and Paschen caught the attention of several British and American spectroscopists and astrophysicists. He visited England in 1895 and America in 1897, to which he returned as a visiting professor at Columbia University in 1907.

Paschen departed for the University of Tübingen in 1901; Runge remained behind. Among his peers, he was like a man without a country. Mathematicians considered him a physicist, and physicists thought of him as a mathematician. By 1904, however, **Hermann Klein** had managed to prevail upon colleagues to bring Runge to Göttingen as the first full professor of applied mathematics in Germany. He held this position until retirement in 1923. His research came to a virtual halt as he became involved with symposia, colloquia, and interaction with peers and students. On his death, Runge was succeeded on the collaborating editor board of the *Astrophysical Journal* (where he had served since 1903) by his former colleague Kayser.

George S. Mumford

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Rushd

➔ **Ibn Rushd: Abū l-Walīd Muḥammad ibn Aḥmad ibn Muḥammad ibn Rushd al-Ḥafīd**

Russell, Henry Chamberlain

Born **West Maitland, New South Wales, (Australia), 17 March 1836**
Died **Sydney, New South Wales, Australia, 22 February 1907**

Henry C. Russell made important contributions to Australian astronomy and meteorology, and played a leading role in the development of Australian scientific societies. The son of the Honorable Bourn Russell, a New South Wales legislator, and Jane (*née* Mackreth) Russell, Henry was educated privately and attended the University of Sydney, graduating with a BA in 1859. One year later, he married Emily Jane Foss; at the time he died, he was survived by her, four daughters, and a son.

In 1859, Russell was appointed computer at the Sydney Observatory; in 1870, he became the observatory director, a post he would occupy until his retirement in 1905. From the start, Russell was equally committed to astronomy and meteorology. In astronomy, Russell began by building up the instrumentation at the Sydney Observatory. The existing 18.4-cm Merz refractor and small transit telescope were joined by a 29.2-cm Schroeder refractor in 1874, a 15.2-cm Troughton and Sims transit telescope in 1877, and a 33-cm astrograph with a 26-cm guidescope in 1890. A two-story wing, complete with new dome, was added to the observatory in 1877. Russell and others at the Sydney Observatory observed comets, eclipses, Jovian features, transits of Mercury and Venus, the η Carinae region, the open cluster κ Crucis, and double stars. In 1871, he and Melbourne Observatory director, **Robert Ellery**, organized an expedition to far north coastal Queensland to observe a total solar eclipse, but inclement weather dashed their hopes on the vital day.

One of the comets that attracted Russell's attention was the great comet C/1881 K1. Russell was the first astronomer to subject comet C/1881 K1 to spectroscopic analysis, his sole foray into the exciting new field of spectroscopic astronomy. Because the account of his observations was published in a local journal, it did not reach a wide international audience.

Australia was well placed to observe the 1874 and 1882 transits of Venus. Russell organized ambitious observing programs for both events. He used the 1874 transit as leverage to gain government funding for new telescopes, and in 1874 equipped and manned four observing stations. All Sydney Observatory stations recorded the transit of 1874; as a result Sydney Observatory data played a key role in **George Airy**'s calculation of the solar parallax. In 1892, the government belatedly published an attractive and well-illustrated book about the 1874 transit. In stark contrast to the successes of 1874, cloudy weather in New South Wales prevented successful observation of the 1882 transit.

Double stars held a special fascination for Russell. Starting in 1870, he began by systematically reobserving those listed in **John Herschel**'s *Cape* monograph. Russell and his assistants then went in search of new double stars, and discovered about 500 of them.

One scientific area that Russell pioneered in Australia was astronomical photography. During the second half of the 1880s, he obtained a series of exquisite images of the Magellanic Clouds and various regions of the Milky Way, some of which were published in *Monthly Notices of the Royal Astronomical Society*.

An ardent supporter of the International Astrographic or *Carte du Ciel* Project, Russell attended the inaugural meeting in Paris in 1887 and pledged the involvement of both Sydney and Melbourne Observatories. But unlike other participating observatories, Russell only purchased the Grubb optics for the astrographic telescope. He then supervised construction of the instrument itself in Sydney. This ambitious project took much of Russell's time in the last decade of his career; it also prevented the Sydney Observatory from effective involvement in astrophysical investigations. Conversely, the commitment to the Astrographic Project ensured the survival of the observatory when the government sought to close it in the late 1920s. Stellar data supplied by Sydney and other participating observatories are now being used in conjunction with Hipparcos space-probe measures to derive useful proper motions.

In a nation where agricultural prosperity was a vital economic ingredient, knowledge of the weather was paramount. Russell dramatically increased the number of weather stations operating in New South Wales – from 55 in 1870 to more than 1,600 by 1898. After 1877, he published daily weather maps in the *Sydney Morning Herald* newspaper, and authored two books on the climate of New South Wales and many research papers on Australian meteorology.

In addition to using scientific instruments, Russell liked to experiment with their design and manufacture. He invented a tide gauge and a number of different meteorological instruments. Between 1878 and 1880, he designed and constructed a horseshoe-style equatorial mounting that foreshadowed the mounting of the 5-m Hale telescope. Russell made the 38.1-cm primary mirror used with the horseshoe mounting.

Apart from astronomy and meteorology, Russell continued the geomagnetic program initiated by his predecessor, George Roberts Smalley (1822–1870), and expanded the observatory's tidal studies to include readings at a number of other ports in New South Wales. He also arranged for the observatory's time service to be extended to the colony's second-largest city, Newcastle, where a time ball was installed.

Russell played a leading role in the Royal Society of New South Wales. For a number of years he served as its president, and in addition he founded its short-lived Astronomy Section. Russell cofounded the Australasian Association for the Advancement of Science and served as its inaugural president. A fellow of the Royal Astronomical Society from 1871, he was elected a fellow of the Royal Society of London in 1886. Russell's contribution to science was further recognized in 1890 when Queen Victoria made him Companion of the Order of Saint Michael and Saint George.

A vigorous and exceedingly blunt person, Russell accumulated some enemies along the way. In 1877, he received a parcel bomb, and in 1889 he was attacked by an observatory worker. His strained relations extended to many in the local amateur astronomical community. During the 1890s, he feuded openly with **John Tebbutt**, arguably Australia's foremost astronomer, and with the Lands Department's leading astronomer, Joseph Brooks. However, after Tebbutt, Russell had greater international visibility than any other Australian astronomer.

Wayne Orchiston

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Russell, Henry Norris

Born **Oyster Bay, New York, USA, 25 October 1877**
Died **Princeton, New Jersey, USA, 18 February 1957**

American astronomer Henry N. Russell demonstrated how a star's brightness is related to its spectral type in the so called Hertzsprung–Russell diagram, invented a method to compute the densities of binary stars, and shaped the development of contemporary astronomy by merging astronomy with astrophysics.

The son of a Presbyterian minister, Russell received his early schooling at an Oyster Bay Dames' School. His interest in astronomy dated from early childhood, when, as a 5-year-old, he viewed with his parents the transit of Venus across the Sun. As a teenager he lived with an aunt in Princeton, New Jersey, where he was educated at Princeton Preparatory School and then Princeton University. His intense focus on his undergraduate studies at the latter earned him not only highest honors from his professors (1897) but also two distinctions from his classmates, who described him both as the least socially adept amongst them and also as "Our Star." Russell also did his graduate work at Princeton University, where he figured out a new way to calculate the orbits of binary stars around each other. His dissertation, "The General Perturbations of the Major Axis of Eros Caused by the Action of Mars" (1900), combined his interests in astronomy and mathematics.

Soon after receipt of his Ph.D., Russell spent 2 years in postdoctoral studies at the Astrophysical Observatory of Cambridge University. There he engaged in a program of measurement of stellar parallaxes (distances), using photographic methods. Working with **Arthur Hinks**, he used the Sheepshanks polar reflector fed by a siderostat, a telescope combination said to combine all the disadvantages of a reflector with all the disadvantages of a refractor. Thus, many of the stellar distances used first in his Hertzsprung–Russell diagram were Russell's own work.

In Cambridge, Russell also studied orbit theory and dynamics with **George Darwin**, who, like Russell's Princeton mentor, **Charles Young**, believed that data should not be collected indiscriminately, as was the practice of most astronomers of the day, but rather with a focus on a specific problem. Some years later Russell would summarize this point of view, first to the membership of the National Academy of Sciences and then to the readers of *Popular Astronomy* (1919):

> The main object of astronomy, as of all science, is not the collection of facts, but the development, on the basis of collected facts, of satisfactory theories regarding the nature, mutual relations, and probable history and evolution of the objects of study.

Russell also used the columns he wrote for nearly a half-century (1900–1943) for *Scientific American* as platforms to promote growth in astrophysics. Likewise, the two-volume textbook, *Astronomy* (1926, 1927), which he coauthored with two colleagues (**Raymond Dugan** and **John Stewart**), changed the focus of the teaching of astronomy through its extensive coverage of astrophysics and stellar evolution.

In 1905 Russell returned to Princeton University, where he spent virtually his entire career until his retirement in 1947. He rose through the academic ranks from instructor (1905), to assistant professor (1908), to full professor (1911) and director of the university observatory (1912). Additional appointments, to research associate of the Mount Wilson Observatory (1921) and to a named Princeton professorship (the C. A. Young Research Professorship) endowed by his undergraduate classmates (1927), followed.

During his first years on the Princeton faculty, Russell's analysis of his trigonometric parallax data led him to discover, contemporaneously with, but independently of, Danish astronomer **Ejnar Hertzsprung**, the correlation between a star's intrinsic brightness and its spectral type. Hertzsprung was first to work out a diagram showing the relationship between temperature and luminosity for a group of stars (1911/1912), but few astronomers came across its publication in a photographic journal. When Russell plotted his diagram in late 1913, leading to the publication of the Hertzsprung–Russell diagram the following year, it had an enormous effect on the scientific community. The diagram remains one of the most important in astrophysics. He also popularized the terms "giant" and "dwarf" in stellar evolutionary vocabulary, though he probably did not coin them.

Before presenting the Hertzsprung–Russell diagram, Russell earlier (1909–1913) used the correlation it displays to revive the late-19th-century theory of stellar evolution developed by **Norman Lockyer** and **August Ritter**. According to this theory as updated by Russell, stars begin life as huge, cool, red bodies. As gravitational contraction leads them to become hotter and denser, their color changes from red, to yellow, white, and blue. Eventually stars contract so much that the perfect gas laws no longer apply, and in their final stages they shrink until they end their lives as small, cool, red bodies. In his 1929 article on stellar evolution in the *Encyclopaedia Britannica*, Russell summarized his understanding of the topic, which became widely accepted. It was replaced by another theory, in which stars evolve from the main sequence to become red giants after exhausting their central hydrogen fuel, in the years around World War II.

Russell went on to apply the new quantum mechanics to astronomical problems, defining modern astrophysics. His work with **Frederick Saunders** led to a theory of atomic spectra, for atoms in which more than one electron contributes to the formation of spectral features, that is still known as Russell–Saunders coupling.

Russell's influence has been much discussed in recent years in connection with the question of whether **Cecilia Payne-Gaposchkin** received enough credit for realizing that, as we currently know, hydrogen is the major constituent of the stars. The then Miss Payne concluded as much for the atmospheres of stars in her 1925 Radcliffe College thesis, but Russell's doubts led her to soften her conclusion. Subsequent work, especially by **Donald Menzel**, also at Harvard College Observatory, by **William McCrea**, studying the solar corona, and by Russell himself with the new quantum mechanics, established the supremacy of hydrogen. Only with Russell's thorough analysis did the result become generally accepted.

In addition to being interested in stellar evolution, Russell was also interested in the broader philosophical issue of cosmic evolution, and his *Solar System and Its Origin* (1935) helped pave the way for subsequent research.

Toward the end of World War I, and in the months following it, Russell served as a consulting and experimental engineer in the Army Aviation Service's Bureau of Aircraft Production. There his studies of aircraft navigation problems required him to make observations in open aircraft at altitudes as high as 16,000 ft. Aside from this hiatus, his professional life focused exclusively on astronomy and astrophysics. One field of lifelong interest was binary stars. Russell worked out a method to calculate their masses by studying their orbits, and another to compute distances from Earth by using both orbits and masses. He did trailblazing work on eclipsing variables – binary star pairs in which one member periodically hides the other from the viewpoint of Earth, causing variations in brightness. Russell's last published paper was on binary stars in the Magellanic Clouds.

Russell's connection with Mount Wilson Observatory, which began 3 years after World War I ended, led him to spend several months a year there for the next two decades, until the United

States entered World War II in 1941. During his time in southern California, at the request of the observatory's director, **George Hale**, Russell assisted the staff members in sorting through the spectroscopic data gathered there over the years in order to teach them how to apply cutting-edge physical theory to astronomy. Russell set an example by analyzing line spectra to uncover atomic structure with a view to extending a theory of Indian astronomer **Meghnad Saha**, which demonstrated the role temperature and pressure play in stellar spectra. Russell's quantitative analysis at Mount Wilson Observatory of the abundance of the elements in the solar atmosphere also helped transform theoretical astrophysics into a recognized field.

Although Russell turned down offers to direct the observatories at Harvard and Yale, which were much larger than Princeton's, he nonetheless played a role at Harvard Observatory that was similar to the one he played at Mount Wilson Observatory. In 1921, the same year Russell's association with Mount Wilson Observatory began, his first prominent graduate student, **Harlow Shapley**, was appointed director of the Harvard College Observatory. Shapley immediately put Russell on the visiting committee, where he would exert significant influence in replacing the entrenched habits of the past with newer research perspectives. Other students of Russell's at Princeton University also went on to careers in the major astronomical institutions in the United States, helping to spread Russell's conviction that astronomy and astrophysics should be indistinguishable and that astronomical research should be grounded in theory as well as empiricism.

Unlike his grandfather, father, and brothers, Russell did not choose the Presbyterian ministry as a profession, and he rejected the idea of life after death. During the 1920s at Princeton University, he advocated abolishing compulsory undergraduate chapel attendance, arguing the pointlessness of preaching to a captive but uninterested audience. Nonetheless, he lectured frequently on the ways in which science supported religion and morality, particularly in uncovering the unified design of nature. His lecture series on this subject, published as *Fate and Freedom* (1927), also explores the conflict between the idea of a deterministic universe and the belief in free will. He argued by analogy that free will was as real as the pressure of a gas or other statistical physical phenomena.

Russell and his wife, born Lucy May Cole, had four children, Lucy May, Elizabeth Hoxie, Henry Norris, and Emma Margaret, who married astronomer Frank Edmondson and remained a presence in the astronomical community until her death in 1999.

Russell's transformational leadership in the astronomical community earned him the sobriquets "the general" and "the dean of American astronomers." More than any other astronomer of his generation, he changed astronomy from a discipline based on data collection with telescopes to one driven by physical theory. His own Ph.D. students included Menzel, **Lyman Spitzer**, **Charlotte Moore**, and Louis C. Green (of Swarthmore College and source of the anecdote that Russell was capable of falling asleep during his own lectures).

The Henry Norris Russell Lectureship, given for lifetime achievement, is the American Astronomical Society's highest prize.

Naomi Pasachoff and *Jay M. Pasachoff*

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Russell, John

Born **1745**
Died **1806**

In 1866, **Johann Schmidt** claimed that the telescopic appearance of lunar crater Linné had changed since its depiction in the work of **Gotthelf Lohrmann** and **Johann von Mädler** mere decades before. Evidence against such a historical event on the Moon was provided by English artist John Russell. His 1788 drawing was discovered to show Linné much as Schmidt himself had rendered it.

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Rutherford, Ernest

Born **Spring Grove near Nelson, New Zealand, 30 August 1871**
Died **Cambridge, England, 19 October 1937**

British Empire chemist and physicist Ernest Rutherford received the 1908 Nobel Prize in Chemistry for work on disintegration of the elements and chemistry of radioactive substances, but he is probably best known within astronomy for Rutherford scattering (of one nucleus by another) and his model of the atom that put all the positive charge, and most of the mass, at the center with a cloud of negative charge (electrons) around it. This concept led to the Bohr atom and so to the possibility of understanding conditions under which various spectral features can be produced.

Rutherford was the fourth of 11 children of a British immigrant family. His father was a technician and his mother a teacher. After attending local schools and high schools, and receiving his B.A. in 1892 and B.S. in 1894 at Canterbury College in Christchurch, New Zealand, Rutherford won a scholarship to Cambridge University in

England. There his teacher was the famous physicist J. J. Thomson. Thomson asked Rutherford in 1896 to investigate with him the effect of X-rays, just discovered by Wilhelm C. Röntgen (1845–1923), on the discharge of electricity in gases. This collaboration led Thomson to the discovery of the electron, and Rutherford to the development of an improved quantitative measuring method for ionization processes. As a consequence of this work, Rutherford turned to the study of the atomic structure, and the use of the new rays discovered by Antonie H. Becquerel (1852–1908) in 1896 and soon after named "radioactivity" by Marie Curie (1867–1934).

In 1898, Rutherford accepted a professorship at McGill University in Montreal, Canada. There he began an important series of experiments on the radiation of radioactive elements, beginning with uranium. Soon Rutherford discovered two types of radiation: The so called α radiation with a short range, and the β radiation with a longer range. (A third type, γ radiation, was found by Paul Villard [1860–1934] in 1900.) He also found that thorium and other radioactive elements emitted a gaseous radioactive product, named by him as emanation. In 1901–1902 Rutherford, together with his colleague Frederick Soddy (1877–1956), developed their disintegration theory of radioactivity. In 1903, Rutherford demonstrated that α particles carry positive charge. In 1907, Rutherford became professor of physics at Manchester University, England. At Manchester he developed a school for research into radioactivity.

Together with coworkers and assistants like Hans Geiger (1882–1945) and Ernest Marsden (1889–1970), Rutherford intensively investigated α particles (helium nuclei). As a consequence, in 1911 Rutherford presented a new model of the atom. (Former models had atoms of roughly uniform density, *e. g.*, Thomson's plum-pudding model, while in Rutherford's the positively charged particles are concentrated.) According to this theory, positively charged particles are concentrated in the massive center of an atom, while negatively charged particles orbit this nucleus at a relatively great distance. Two years later **Niels Bohr**, at that time a guest at Manchester University, combined this with the new quantum theory and introduced his new model, which became standard.

Rutherford made his next fundamental discovery in 1918/1919: He observed that the nuclei of certain light elements could be "disintegrated" by the impact of energetic α particles, and that protons were emitted during this process. This was the realization of artificial transmutation of one element into another. In 1925, his pupil **Patrick Blackett** confirmed this result with the help of a cloud chamber.

In 1919, Rutherford succeeded Thomson in the chair of physics at Cambridge University and became the director of the Cavendish Laboratory. Rutherford attracted a lot of young physicists to the Cavendish Laboratory, and he was the motivating central figure of this circle of talented researchers, among them the later Nobel Prize Laureates Blackett, John Cockcroft (1897–1967), James Chadwick (1891–1974), Petr Kapitsa (1894–1984), Cecil F. Powell (1903–1969), and Ernest Walton (1903–1995). Virtually it was Rutherford who created nuclear physics as a special discipline within physics.

Rutherford was elected fellow of the Royal Society in 1903. (He was its president from 1925 to 1930.) He was awarded its Rumford Medal (1904) and Copley Medal (1922).

Rutherford held honorary doctorates from several universities, among them Pennsylvania, Wisconsin, Birmingham, Giessen, Copenhagen, Oxford, Toronto, Cape Town, and London. In 1931, he was created First Baron Rutherford of Nelson. Rutherford was married to Mary G. Newton of New Zealand, and they had one daughter who married **Ralph Fowler**.

Horst Kant

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Rutherfurd, Lewis Morris

Born **Morrisania, New York, USA, 25 November 1816**
Died **Tranquility, New Jersey, USA, 30 May 1892**

Amateur astronomer Lewis Rutherfurd pioneered the use of photography and spectroscopy.

During his student days, Rutherfurd showed a distinct aptitude for science and became an assistant to the Professor of physics and chemistry at Williams College. After graduating at age 18, however, he went on to study law and from 1837 he conducted a successful practice in New York City. Even so, he maintained an interest in science, especially astronomy, and counted among his friends the famous telescope maker Henry Fitz, whose optical methods he learned, and the astronomer **Benjamin Gould**. Rutherfurd was also an active long-term correspondent with the chemist Josiah Willard Gibbs and the physicist Ogden Nicholas Reed, who suggested and encouraged his work in spectroscopy.

Rutherfurd married Margaret Stuyvesant Chanler in 1841, and it was chiefly concern for her health that led him to give up his law practice in 1849 and to embark upon 7 years of foreign travel. While in Europe, he visited observatories and acquired a good background in astronomy and optics that would later prove of value. On his return to the United States in 1856, he built his own observatory, equipped it with an 11.25-in. Fitz refractor, and devoted the rest of his active life to astronomy. Rutherfurd was a capable visual observer; in 1862 and 1863 he reported useful measurements of Sirius B, which had only recently been discovered by **Alvan Clark** while he was testing the

18.5-in. objective being made for the University of Mississippi (and subsequently sold to the Chicago Astronomical Society for use in the Dearborn Observatory). Gould credited Rutherfurd's seven measures of the position of Sirius B as among the most important early confirmations of the discovery. They were the earliest usable observations of Sirius B with any telescope with an aperture less than 15 in. and met the high standards of **Sherburne Burnham** when the latter prepared his catalog of double stars some four decades later.

Two years later, Rutherfurd took up celestial photography in earnest. As photographic emulsions of that time were sensitive only to blue light, and refractors constructed for visual use at long wavelengths did not give sharp photographic images, his first such results were generally disappointing – with the exception of some images of the Sun and the Moon taken at reduced aperture. Accordingly, he undertook a series of important demonstrations to distinguish between the visual and blue focus. He also conducted a number of experiments to determine the actinic or photographic focus of his refractor. The care exercised in this respect, first showcased at the solar eclipse of 1860 in Labrador, resulted in excellent photographs of that event taken with a 4.25-in. refractor. (Rutherfurd increased the spacing of the lens elements to move the instrument's focus to a compromise position between the visual and actinic focal points.) That success led Rutherfurd to construct the first refracting telescope designed solely for photographic work. Working with Henry Fitz and his son Harry, Rutherfurd figured the lens using a spectroscope, a technique that was later applied to advantage by Alvan Clark and his sons. They completed that telescope in 1864; it had an aperture of 11.25 in., and was a total success, yielding excellent images of the Moon that were 1.7 in. in diameter on the photographic plate, and giving good images of stars to the ninth magnitude.

But such instruments are useless for visual work. Hence in 1868, Rutherfurd, again working with Harry Fitz, completed a 13-in. visual refractor that could be converted to a photovisual telescope by the attachment of a corrector lens to the front of the objective. (The design was later used by the Clarks as the basis for the 36-in. Lick refractor.) By 1877, Rutherfurd had accumulated over 1,400 photographs of celestial objects, chiefly the Moon and star clusters.

After 1861, Rutherfurd became more interested in the spectroscopic work of **Robert Bunsen** and **Gustav Kirchhof**, and from 1862 he began spectroscopic studies of the Sun, Moon, Jupiter, Mars, and some fixed stars. From his early spectroscopic work, Rutherfurd devised a stellar classification scheme based on gross differences in bright star spectra, which Gould and **Julius Scheiner** credited as preceding a very similar though more refined scheme proposed by **Angelo Secchi**.

With an ingenious spectrograph employing six prisms filled with carbon disulfide, Rutherfurd produced a solar spectrum that exceeded all previous results. In 1864 at a meeting of the National Academy of Science, Rutherfurd displayed an unpublished photographic solar spectrum that had three times the number of lines noted by Kirchhof and Bunsen in their spectrum of the Sun.

To assist his spectroscopic work, Rutherfurd then began to produce gratings from a screw-driven ruling machine rather than the lever-driven machines common to that era. His best efforts produced gratings with up to 17,000 lines per inch. Rutherfurd's gratings, unsurpassed until the advent of **Henry Rowland** and his concave spectral gratings, were generously distributed to other scientists who pressed them into various types of spectroscopic service.

Rutherfurd was convinced that photographic plates offered a solution to problems in astrometry. He pursued that proposition both through his experimentation with the photographic recording of stellar clusters, and through development of machines for making very precise measurements of star image positions on photographic plates. Though his efforts to demonstrate the efficacy of that process were clouded by the concerns of other astronomers about the stability of photographic films of the period, his vast collection of plates of stellar clusters has been useful in efforts to determine proper motions of stars in clusters over a century after their first exposure. The soundness of Rutherfurd's original concept has since been well demonstrated.

Rutherfurd made his last observations in 1878. He donated the 13-in. refractor to Columbia College Observatory in 1883, and 7 years later presented his entire plate collection, together with 20 folio volumes of unreduced plate measures, to the same institution.

When the National Academy of Science was formed by an act of the United States Congress in March 1863, Rutherfurd was honored by his selection for membership in the first group of 50 American scientists named in that congressional act. He was a foreign associate of the Royal Astronomical Society and received the Rumford medal of the Royal Society of London. Columbia University conferred its Doctor of Laws *honoris causa* upon Rutherfurd in 1887.

Richard Baum

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Rydberg, Johannes [Janee] Robert

Born **Halmstad, Sweden, 8 November 1854**
Died **Lund, Sweden, 28 December 1919**

Swedish physicist Johannes Rydberg calculated the amount of energy required to unbind the single electron of hydrogen, and this amount (13.6 eV) is often given his name as the Rydberg constant (alternatively 109,678 cm^{-1}). More recently, the phrase Rydberg matter has been used to describe neutral gas in which the electrons are located in states of very high excitation far from their nuclei.

Rydberg was the son of Maria Beata Andersson and Sven R. Rydberg, a local tradesman and boatyard operator, who died when his son was four. He married Lydia E. M. Carlsson in 1886, and they had a son and two daughters.

Rydberg studied and worked all his life at Lund University. He first went there in 1873 after completing his gymnasium studies in Halmstad; he was awarded the Ph.D. degree in mathematics in 1879, becoming a *docent* (lecturer) in mathematics in the following year. His interests progressively turned toward mathematical physics and in 1882 Rydberg was made *docent* in physics until he was appointed in 1901 to an extraordinary professorship in physics as well as to the directorship of Lund's department of physics. From 1876 to 1897, he was also assistant at the university's Physics Institute. When in 1908 a new law eliminated the rank of extraordinary professor, Rydberg automatically became an ordinary professor, a position he retained until his death, although from 1914 he was sick and was often absent from the university. Rydberg was a member of the Royal Society of London (1919), and a leading figure of the Physics Society of Lund.

While contemporary Swedish spectroscopists of renown, **Anders Ångström**, Robert Thalen, and Barnhard Hasselberg, carried out mainly experimental programs of charting the spectra of different elements that are found in the sun, Rydberg largely relied on other scientists' measurements to study the structure of spectra, in particular to find arithmetic formulae describing the wavelengths of lines and to compare them with the physical and chemical properties of elements. A mathematician by training, Rydberg carried over a mathematical approach to spectroscopy. He most notably concerned himself with the numerical analysis of regularities in spectra, producing what became known as Rydberg's formula. From the 1860s, spectroscopists had searched for patterns or regularities in the positions of spectral lines, often hoping to find harmonic ratios. **Johann Balmer** notably put forward in 1885 a formula accounting for the hydrogen spectrum. In 1889, Rydberg proposed a more general formula describing all series of all atomic line spectra, which contributed to organize the mass of available spectroscopic measurements, but which failed to lead him to his stated goal, the understanding of the nature and properties of the atom. This work, together with contemporary researches into spectral regularities by Walther Ritz, as well as Heinrich Kayser and **Carl Runge**, subsequently proved central in the elaboration of atomic theories from the 1910s onward. **Niels Bohr**'s theory of atomic structure (1913), combining **Ernest Rutherford**'s nucleus with Max Planck's quantum, for the first time gave an interpretation of Rydberg's formula and confirmed Rydberg's belief that spectral characteristics were useful in the investigation of atomic structure and properties. The numerical value of the Rydberg constant depends upon the charge and mass of the electron (not yet discovered when he put forward his formula) and Planck's constant. Though it was to Rydberg an empirical result from laboratory experiment, the constant can be derived using Bohr's theory of atomic structure.

Charlotte Bigg

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S

Sabine, Edward

Born **Dublin, Ireland, 14 October 1788**
Died **Richmond, (London), England, 26 June 1883**

Irish polymath Edward Sabine was the first to point out the correlation between the 11-year solar activity (sunspot) cycle and a similar cycle in the behavior of the Earth's magnetic field.

Sabine's education was completed at the Royal Military Colleges of Marlow and Woolwich, England. On 22 December 1803, he was commissioned as a second lieutenant in the Royal Artillery, becoming a captain one decade later. He would ultimately achieve the rank of major general (1859).

After his services in the war of 1812 against the United States, Sabine was chosen as astronomer on the first expedition (1818) sponsored by the Royal Society of London to search for the Northwest Passage. He served in the same capacity on the subsequent expedition from 1819 to 1820. On these voyages, he made his first observations of terrestrial magnetism that were later described before the Royal Society. Sabine reached the important conclusion that, through extensive travel, he might be able to study the Earth as an astronomical body. He argued for a worldwide study of magnetism, to be conducted through a network of widely separated stations. This idea was furthered by **Alexander von Humboldt**, who promoted the concept and aided the establishment of magnetic observatories from Germany to Beijing.

Sabine spent the years 1821 and 1822 on another mission for the Royal Society to determine the true figure of the Earth from timings of the period of a pendulum's swing. His observations were carried out at several sites on or near the Equator along the coasts of Africa and South America. He then extended those observations to Greenland and Norway. For this work, he was awarded the Royal Society's Copley Medal.

During 1825, Sabine worked with Sir **John Herschel** on a joint commission of the British and French governments charged with determining the longitude difference (by means of rocket signals) between the observatories located at Paris and Greenwich, England. Two years later, Sabine resumed his pendulum observations. In the interim, Sabine had married Elizabeth Juliana Leeves who assisted him in his work. She died in 1879; the couple had no children.

But Sabine did not lose sight of his goal of assembling worldwide magnetic data. He joined the British Association for the Advancement of Science (created by Charles Babbage as an alternative to the Royal Society). Years later, Sabine promoted reforms in the election of fellows of the Royal Society to answer Babbage's complaints.

By 1835, the British Association (at Sabine's urging) passed a resolution calling for the government to open magnetic and meteorological observatories in the colonies. When this prod proved ineffective, Sabine exerted his influence upon the Royal Society, where he had been secretary since 1827. Again, nothing happened until Herschel's return from South Africa in 1838, whereupon he gave his support, and the project was launched. An early result was the construction of a magnetic observatory at the University of Toronto for studies of the aurora borealis.

Sabine's political adroitness was further demonstrated regarding the King's Observatory at Kew. This facility had been constructed so that King George III, an amateur astronomer, could observe the 1769 transit of Venus. Thereafter, it had been used primarily as an educational center for the Royal family and to house George III's collection of scientific instruments. In the early 1840s, Sabine had the idea of converting the structure into a magnetic observatory and training personnel in its use. He suggested that the Royal Society take over the facility. Herschel objected on grounds that this was too limited a venture; the Royal Society declined to act. In turn, Sabine took his proposal to the British Association, of which he was then the general secretary. The association acquired the site in 1842 and managed the observatory until 1871, when it was transferred to the Royal Society, where Sabine was completing a 10-year term as president.

Sabine's correlation of magnetic data from the Toronto and Hobarton (Tasmania) observatories with measurements of sunspot activity compiled by German astronomer **Heinrich Schwabe** led to his most important discovery. In 1852, Sabine announced to the Royal Society that the 11-year sunspot cycle was directly correlated with the newly discovered geomagnetic cycle. This provided the first evidence of solar–terrestrial relationships (beyond gravitational attractions) and ushered in further studies of these phenomena.

Among other honors, Sabine was awarded a Royal Medal in 1849 and the Lalande Prize of the French Academy of Sciences. He was named an honorary or associate member of numerous foreign academies and scientific institutes. Sabine was knighted in 1869.

Sabine’s brother Joseph, a naturalist who accompanied him to the Arctic, named a seagull he first sighted in 1819 after Edward; a lunar crater was likewise named for him in 1935.

George S. Mumford

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Sacrobosco

➔ **John of Holywood**

Ṣadr al-Sharīˁa al-Thānī: ˁUbaydallāh ibn Masˁūd al-Maḥbūbī al-Bukhārī al-Ḥanafī

Died **Bukhara, (Uzbekistan), 1346/1347**

Ṣadr al-Sharīˁa (al-thānī, *i. e.*, “the Second”) was a theoretical astronomer and religious scholar who created original and sophisticated astronomical theories of time and place, and under circumstances that have long been considered devoid of original scientific research. Ṣadr was famous for his commentaries on Islamic jurisprudence (*sharīˁa*, hence his nickname Ṣadr al-Sharīˁa, “preeminent [scholar] of the *sharīˁa*”). He was called “the Second,” after his great-great-grandfather, Ṣadr al-Sharīˁa al-Awwal (“the First”). Ṣadr also wrote on Arabic grammar, *kalām* (theology), rhetoric, legal contracts, and *ḥadīth* (prophetic traditions).

Ṣadr’s astronomical writings are found in the third volume of his three-volume encyclopedia of the sciences, the *Taˁdīl al-ˁulūm* (The adjustment of the sciences). The first two volumes dealt with logic and *kalām*. The third volume was called *Kitāb Taˁdīl hay'at al-aflāk* (The adjustment of the configuration of the celestial spheres).

Ṣadr al-Sharīˁa represents one of several theorists who worked within the astronomical tradition of theoretical astronomy (*hay'a*). This tradition had its roots within the early Islamic period, especially with **Ibn al-Haytham**, but it began to flourish among the group of astronomers who were assembled at the Marāgha Observatory in northwestern Iran by the polymath **Naṣīr al-Dīn al-Ṭūsī**. One of the major issues that was of concern to these theorists was the irregular motion produced in several of **Ptolemy**’s models, such as that brought about by the equant, and they sought to substitute models that would adhere to the physical principle of uniformity of motion in the heavens. Ṣadr frequently cites two works from this tradition – Ṭūṣī’s *al-Tadhkira fī ˁilm al-hay'a* (Memoir on astronomy), and *al-Tuḥfa al-shāhiyya* (The imperial gift) of **Quṭb al-Dīn al-Shīrāzī**. He does this in order to correct their work, and to present solutions to problems they missed.

In the *Kitāb Taˁdīl hay’at al-aflāk*, Ṣadr critically reviews the planetary models of his predecessors, especially Ptolemy, and points out their weaknesses. He then describes his own models that are meant to rectify them. The most significant problems Ṣadr addresses are: the lunar prosneusis point, the equant; planetary latitude theory, and the motion of Mercury.

In the case of the Moon, Ptolemy proposed that one orb rotate uniformly around the center of the Universe while maintaining a constant distance around another point, the deferent center; Ṣadr objects to this since it produces irregular motion in the celestial realm. Furthermore, rather than measure the motion in anomaly from the visible apogee of the lunar epicycle, Ptolemy measured it from the mean epicyclic apogee aligned with a point, the prosneusis, introduced into the model solely for this purpose. In offering a physically consistent model, Ṣadr employed both a rectilinear and a curvilinear “Ṭūsī couple.” Both of these devices combined circular motions in such a way as to produce a compound motion that oscillates along a line. In the rectilinear case, a smaller circle, internally tangent with a larger circle, rotates in such a manner as to produce linear motion; and in the curvilinear case, concentric spheres are made to rotate in such a way as to produce an approximate curvilinear motion along the surface of the epicycle sphere.

In the case of the upper planets (Mars, Jupiter, and Saturn), for which Ptolemy was compelled to introduce the equant point, Ṣadr followed **Mu'ayyad al-Dīn al-ˁUrḍī** and Shīrāzī, without acknowledgment, and employed an epicyclet (an epicycle on an epicycle).

The Ptolemaic theory of planetary latitude and the revisions to it made by Islamic successors attempted to provide models for the planets’ deviations from the ecliptic and involved complex, nonuniform spherical motions. Ṣadr summarized the work of his three predecessors and offered his own observations. As of this date, however, this problem has been insufficiently studied, so the significance of Ṣadr’s work on the theory of planetary latitude remains obscure.

The case of Mercury involved several equant-like problems and thus was particularly complicated. Ṣadr employed two geometrical tools invented by his predecessors – the “ˁUrḍī lemma” and the spherical “Ṭūsī couple” to arrive at his solution. Late medieval Islamic astronomy has as yet been insufficiently studied to assess fully the possible influence of Ṣadr on subsequent astronomers, such as **Khafrī** and others.

Ṣadr’s work is also significant in that it provides a counterexample to two long-standing paradigms of Islamic intellectual history. First, Ṣadr, who was a prominent religious scholar, contradicts the conclusions of traditional Orientalist scholarship, according to which the Islamic religious establishment was virtually completely opposed to science, and this opposition was supposedly a major factor in the decline of science in Islam. Second, Ṣadr stands as a major counterexample to the prevalent view of Islamic historiography whereby Islamic culture enjoyed a brilliant flourishing from the 9th century until the 11th century, but then suffered unmitigated decline in large part due to the critiques of rational science and philosophy by such religious scholars as Ghāzālī (died: 1111). Ṣadr clearly represents a very high level of mathematical and scientific sophistication within a tradition that falls well within the period of supposed decline.

Glen M. Cooper

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Safford, Truman Henry

Born **Royalton, Vermont, USA, 6 January 1836**
Died **Newark, New Jersey, USA, 13 June 1901**

American astronomer Truman Safford was the first director of the Dearborn Observatory (now part of Northwestern University), and later the director of Williams College's Hopkins Observatory. His 1888 catalog of north polar stars showed groups of stars with common proper motions. Born with a photographic memory, while at the telescope, Safford had no need for stellar coordinates from the *Nautical Almanac*; he had memorized all of them.

A sickly child from birth, Safford's education was mainly from his family's home library. His prodigious mental computational ability was evidenced by his preparation, by age ten, of almanac's for various cities including Boston, Cincinnati, and Philadelphia. This brought him to the attention of **Benjamin Peirce**, who arranged for Safford's further preparatory education and enrollment in Harvard. After graduating from Harvard University, Safford was employed at the Harvard College Observatory. His computation of the irregularities in the proper motion of Sirius in declination confirmed prior predictions of an unseen companion by **Wilhelm Bessel** and **Christian A, Peters** based on its variations in right ascension, and preceded the accidental discovery of the first observed white dwarf star, Sirius B, by **Alvan Graham Clark**. When the observatory director, **George Bond**, died prematurely, Safford completed and edited Bond's highly praised observations of the Orion Nebula for publication in the *Harvard Annals*.

Safford's directorship of the Dearborn Observatory was frustrated by an inadequate dome for what was then one of the largest refracting telescopes in the world, the 18.5-in. Clark refractor with which Sirius B was discovered. Because the dome could not be easily moved, Safford was forced to use the telescope in a transit mode. His search for new nebulae in the manner of **William Herschel**'s sky sweeps was essentially the most appropriate use of the telescope under the circumstances. Safford is credited with the discovery of 49 nebulae.

When the Great Chicago Fire reduced the ability of the Chicago Astronomical Society to financially support the Dearborn Observatory, Safford resigned, seeking other salaried employment to support his family. From 1872 to 1875, he provided astronomical support to the United States Army Corps of Engineers in their preparation of topographical maps of the western United States. In 1876, Safford was appointed director of the Hopkins Observatory and professor of astronomy at Williams College, where he served for the remainder of his life.

Thomas R. Williams

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Safronov, Viktor Sergeyevich

Born **Velikiye Luki, Russia, 11 October 1917**
Died **1999**

Russian solar-system cosmogonist Viktor Safronov was a protégé of **Otto Schmidt**. In his 1968 *Evolution of the Protoplanetary Cloud* and the *Formation of the Earth and Planets*, Safronov quantified the theory for planetary formation from the accumulation of planetesimals, an idea generally attributed to **Thomas Chamberlin** and **Forest Moulton** around 1900. The Safronov theory includes the evolution of the planet's mass, obliquity, and temperature as a function of the rate of accretion.

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Ṣāghānī: Abū Ḥāmid Aḥmad ibn Muḥammad al-Ṣāghānī [al-Ṣaghānī] al-Asṭurlābī

Flourished **Ṣāghān (near Merv, Turkmenistan)**
Died **Baghdad, (Iraq), 990**

Ṣāghānī was a mathematician, astronomer, and astrolabe maker. The 13th-century biographer al-Qifṭī reports that Ṣāghānī was an expert in geometry and cosmology (*ʿilm al-hay'a*) and was the inventor and maker of instruments of observation. He had a number of students in Baghdad. He was also one of the outstanding astronomers at the observatory (*bayt al-raṣd*) built by order of the Būyid ruler Sharaf al-Dawla (982–989) at the extremity of the garden of the royal palace.

The Sharaf al-Dawla Observatory was the first in the history of Islam to have official status of some kind. According to al-Qifṭī, its program included the observation of the seven planets. This task was entrusted by Sharaf al-Dawla to **Wījan ibn Rustam al-Kūhī**, the director (*ṣāḥib*) of the observatory and the leader of the astronomers working at the institution in 988. One of the project's achievements was the observation of the Sun's entrance into two signs (the sign of Cancer and about three months later the sign of Libra). Two official documents were drawn up to testify to the accuracy of the procedures, and Ṣāghānī was one of the signatories.

According to **Bīrūnī**, Ṣāghānī used a ring with subdivisions into 5 min and diameter of 6 *shibr*, *i. e.*, about 145 cm, for the determination of the obliquity of the ecliptic and also for measuring the latitude of Baghdad. The date of the observation is given as 984/985, and the site is specified as "Birka Zalal" in western Baghdad. Bīrūnī also mentions that Ṣāghānī determined the lengths of the seasons using similar methods.

Ṣāghānī is frequently associated with a determination of the obliquity of the ecliptic by an observation using a 21-ft. quadrant in the year 995. However, this observation with a quadrant of a very similar size has also been attributed to Ṣāghānī's contemporary, the great astronomer and mathematician **Abū al-Wafā' al-Būzjānī**, who died in 997 or 998. As Ṣāghānī died in 990, the latter attribution must be the correct one.

Ṣāghānī's work on the astrolabe, entitled *Kitāb fī kayfiyyat tasṭīḥ al-kura ʿalā saṭḥ al-asṭurlāb*, was dedicated to ʿAḍūd al-Dawla (977–983). In this treatise in 12 sections, Ṣāghānī describes his own method, which he claims to be new, of projecting the sphere onto the plane of the astrolabe. With this technique, conic sections (ellipse, parabola, and hyperbola), in addition to points, straight lines, and circles, are formed by taking as the "pole of projection" not one of the poles but some other point on the line joining them. In his book *Kitāb fī istīʿāb al-wujūh al-mumkina fīṣanʿat al-asṭurlāb*, Bīrūnī states that no one can deny that Ṣāghānī is the inventor of this projection. Ṣāghānī seems to have encouraged Bīrūnī to develop a special type of projection, the orthographic or cylindrical.

Ṣāghānī's treatise, *Risāla fī al-sāʿāt al-maʿmūla ʿalā ṣafā'iḥ al-asṭurlāb*, of which only the first chapter is extant, deals with the circular arcs that represent the hour lines on an astrolabe plate. Ṣāghānī states that many people in his time believed that these arcs pass through the projections of the north and south points. With a very clear and practically oriented explanation, he then proves that on astrolabe plates for the temperate latitudes the circular arcs for the ends of the first, second, and third seasonal hour cannot all pass through the projections of the north and south points.

Ṣāghānī also wrote a work in three parts on planetary sizes and distances.

Roser Puig

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Saha, Meghnad N.

Born **Seoratali near Dacca, (Bangladesh), 6 October 1893**
Died **near New Delhi, India, 16 February 1956**

Indian theoretical physicist and astrophysicist Meghnad Saha is eponymized in the Saha equation, which permits calculation of the degree of ionization in a gas that is at a well-defined temperature and density. It is of enormous importance in analyzing the spectra of stars and nebulae and permitted **Cecilia Payne-Gaposchkin** to show that the stars consist primarily of hydrogen and helium.

Meghnad Saha was educated in local schools in Dacca – a private one after participation in a nationalist demonstration caused loss of his scholarship at a government school. He enrolled at Presidency College in 1911, with a small scholarship, awarded after Satyen Bose, a lifelong collaborator, and he applied in person. Saha received an M.Sc. in 1915, having always been an outstanding student, and was appointed as a lecturer, first in mathematics and then in physics, at the University of Calcutta in 1916. Several papers over the next 2 years on the spectrum of the Sun and the quantum theory of light earned him a D.Sc. from Calcutta in 1918, where he and Bose also prepared English translations of papers on special and general relativity by **Albert Einstein** and **Hermann Minkowski**.

Before leaving Calcutta, Saha had already begun the work for which he is remembered. This was completed, under scholarships and fellowships awarded from India, at Imperial College, London, and in the laboratory of **Walter Nernst** in Berlin. It resulted in a series of six papers, published in 1920/1921, in which he laid out a theory of ionization of gases and applied it to the spectra of the Sun and stars. Saha's thinking had been guided by a 1916 discussion of the dissociation of molecules by J. Eggert, and he drew an analogy to conclude that the ratio of the number of ionized atoms to neutral atoms of some particular element would depend both on the number of electrons present (more electrons favoring neutral atoms) and, exponentially, on the ratio of the amount of energy required to ionize the atoms to the temperature of the gas (higher temperature favoring ionized atoms).

Saha returned to Calcutta University as Khaira Professor of Physics in 1921, moving to the University of Allahabad as professor and head of the physics department in 1923, and returning once again to Calcutta as Palit Professor of Physics in 1938, from which position he retired in 1953. Saha continued to work on a variety of topics in physics and astronomy, including radiation pressure, spectroscopy, molecular dissociation, radioactivity, ionospheric physics, and the solar corona, but the remainder of his life's work really focused on teaching, service to the scientific community of India, and, finally, public service. He was instrumental in the founding of the organizations now known as the National Academy of Sciences, the Indian National Science Academy, the Indian Physical Society, and the Saha Institute of Nuclear Physics. He was elected a member of the Indian Parliament as an independent candidate in 1952. Saha's career in many ways was a mirror of the growth of scientific research and progress in India, and he died *en route* to the Office of the Planning Commission. Saha was elected a fellow of the Royal Society (London) in 1927 and has a lunar crater named for him. He married Radha Rani in 1918; they had three sons and three daughters. His equation is probably as famous outside of astronomy as in, because it is also applicable to fusion plasma, flames, explosions, and partly ionized gases in many other contexts.

The Meghnad Saha Archive is at the Saha Institute of Nuclear Physics, Calcutta.

Yatendra P. Varshni

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Sahl

➜ **Ibn Sahl: Abū Saʿd al-ʿAlāʾ ibn Sahl**

Ṣāʿid al-Andalusī: Abū al-Qāsim Ṣāʿid ibn abī al-Walīd Aḥmad ibn ʿAbd al-Raḥmān ibn Muḥammad ibn Ṣāʿid al-Taghlibī al-Qurṭubī

Born **Almería, (Spain), 1029**
Died **Toledo, (Spain), July or August 1070**

Ṣāʿid al-Andalusī was a Muslim historian, historian of science and thought, and mathematical scientist with an especial interest in astronomy. Given the near-total loss of his astronomical writings, his claim to recognition in science largely rests on his encouragement and possibly patronage – in his capacity as a well-placed functionary at the Toledan court – of a group of young, precision instrument makers and scientists, the most renowned of whom was Azarquiel (*i. e.*, **Zarqālī**). The precise extent of his involvement in the compilation of the *Toledan Tables* – widely disseminated in Latin Europe during subsequent centuries – remains uncertain, owing to the *Tables*' deficient manuscript tradition and to the fragmentariness of biobibliographic data.

Following in the footsteps of his paternal family, Ṣāʿid pursued the career of a legal official, having received a solid education in the Islamic religious disciplines; in 1068, the Dhannūnid Berber amīr of Toledo, al-Ma’mūn Yaḥyā (reigned: 1043–1075), appointed Ṣāʿid chief religious judge (*qāḍī*) of Toledo, an office his father had held earlier and that he himself was to fill until his death. His civil life thus did not stand out from among many of his contemporaries of similar background. What set him apart was his interest in history, history of science, and science itself, especially astronomy; here it may be recalled that in the present context “science” refers to what in premodern Islam often was termed “the ancient disciplines,” *viz.* the syllabus of Aristotelian philosophy, logic, medicine, the mathematical sciences (including astronomy), and the occult disciplines, *i. e.*, alchemy, astrology, and magic.

The only work of Ṣāʿid’s to survive intact is what has often been called his “history of science”: *Al-taʿrīf bi-ṭabaqāt al-umam* (Exposition of the generations of nations) of 1068. The “nations” here intended are those said to have had a disposition toward the cultivation of learning, such as, Indians, Persians, Chaldeans, Egyptians, Greeks, al-Rūm (“Byzantines” and other Christians), Arabs, and Jews (in contrast to the others not so disposed, *i. e.*, Chinese, Turks, and Berbers). Of his other three nonextant works, he cites two there: *Jawāmiʿ akhbār al-umam min al-ʿArab wa-’l-ʿAjam* (Compendious history of nations – Arab and non-Arab) and *Maqālāt ahl al-milal wa-’l-niḥal* (Doctrines of the adherents of sects and schools). These appear to have treated historical subjects, whereas the third one, *Iṣlāḥ ḥarakāt al-kawākib wa-’l-taʿrīf bi-khaṭa’ al-rāṣidīn* (Rectification of planetary motions and exposition of observers’ errors) adumbrated the astronomical activity of the remaining 2 years of his life, after completion of *Generations*. In *Generations*, Ṣāʿid’s view of history and of the progress of scholarship and science from their earliest appearance among (or revelation to?) humankind up to his own country of al-Andalus (Muslim Iberia) and generation has drawn considerable scholarly attention during the last decade-and-a-half, without the issue of his actual beliefs having been convincingly settled. In particular, Ṣāʿid’s seeming “pessimism” concerning the cultivation of learning and science among his fellow countrymen has called for comment, given the fact that by that time he and Azarquiel must have been engaged in observations for a number of years and the apparent quickening of astronomical activities in his very hometown of Toledo immediately after the completion of *Generations*, for which the name Azarquiel has taken on nearly emblematic status.

As indicated earlier, extant sources provide but disappointingly fragmentary testimony on astronomical activity in Toledo between 1068, the date of Ṣāʿid’s *Generations,* and Azarquiel’s less than voluntary move to Cordova *circa* 1080 because of unsettled conditions under al-Ma’mūn’s dissolute grandson Yaḥyā al-Qādir. Thus Ṣāʿid’s personal contribution to the observations and research as represented by sections of the *Toledan Tables* cannot be determined exactly except in the cases of planetary motions (including the length of the solar year) and the theory of trepidation; one may not stray far from reality in assuming that the title of his treatise *Rectification of Planetary Motions and Exposition of Observers’ Errors* suggests the focus of his astronomical interests and of his contribution to the *Toledan Tables*. Relative ignorance of current relevant scholarship in the Islamic East was a shared Andalusī feature in Ṣāʿid’s lifetime, as evidenced not merely in *Generations* but as demonstrated far more graphically by the *Toledan Tables* themselves.

Lutz Richter-Bernburg

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St. John, Charles Edward

Born **Allen, Michigan, USA, 15 March 1857**
Died **Pasadena, California, USA, 26 April 1935**

American solar physicist Charles St. John made the first, not entirely successful, attempt to measure the gravitational redshift of light coming from the Sun, and compiled a definitive table of wavelengths of solar spectral features. St. John earned a BS from Michigan State College (1887), and an MA (1893) and Ph.D. (1896) from Harvard University, the latter in physics, with a thesis on electric spark spectra. He also studied at the universities of Michigan (1890–1892) and Berlin (1894–1895). St. John initially held teaching positions at the Michigan Normal College (1886–1892) and University of Michigan (1896–1897) before being appointed to an associate professorship in physics and astronomy at Oberlin College, Ohio, in 1897. He became full professor in 1899 and dean of the College of Arts and Sciences in 1906. Both Michigan Normal College and Oberlin College eventually awarded St. John honorary degrees. Among the Oberlin College students who followed him into astronomy was **Alfred Joy**. In the winter of 1908, **George Hale** set his sights on St. John to fill the position of solar physicist at his new Mount Wilson Observatory in California.

St. John had some difficulty with the decision to leave his administrative and teaching responsibilities, but within the year had succumbed to the attractions of working with Hale and

Walter Adams. He held a staff position at Mount Wilson from 1908 to 1930 and a research associateship from retirement until the time of his death. St. John was the first Mount Wilson staff member to die.

The most substantial product of St. John's years at Mount Wilson was the 1930 revision of **Henry Rowland**'s Table of Solar Lines, which increased the number of chemical elements identified in the Sun from 36 to 51. He also made extensive observations of solar rotation, *via* Doppler shifts, and showed that the solar photosphere, reversing layer, and lower chromosphere rotate at different speeds. Adams and St. John attempted an analysis of the atmosphere of Mars in 1925, reporting more water vapor and molecular oxygen than were revealed by later work.

St. John's spectrograms of the Sun, with high resolution in both wavelength and position, readily confirmed the effect associated with the name of **John Evershed**, in which gas flows outward from sunspot centers. He also found that the direction of flow reverses above the spots, confirming a 19th-century model for their structure due to **Angelo Secchi**.

Most delicate of all was the observational search for a slight redshift of solar absorption lines expected because the light would lose energy in climbing out of the solar gravitational field. The amount of shift predicted by **Albert Einstein**'s theory of general relativity (and indeed by Newtonian gravity) is only 0.02 Å for a line at 5,000 Å, or the equivalent of motion at 1.2 km/s. The rising and falling convective currents throughout the solar atmosphere, as well as the Evershed flows, are of comparable size, and St. John concluded in 1917 that the gravitational shift was not there. Later, looking at a larger number of lines, he believed that it could be separated out from other line shifts and was of about the expected size. This is now known to be the case, but the definitive result is generally attributed to much later work.

St. John was elected to the United States National Academy of Sciences and several other honorary positions as well as serving as president of the commissions of the International Astronomical Union on standard wavelengths and on solar physics for several 3-year terms each. He was active in the Congregational Church, in community affairs (the Oberlin Water Works Board, for instance), and was an enthusiastic amateur of tennis, golf, and billiards.

Katherine Haramundanis

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Salih Zeki

Born **Istanbul, (Turkey), 1864**
Died **Istanbul, (Turkey), 1921**

Salih Zeki was one of the most important mathematicians of the late Ottoman period. He was the founder of the mathematics, physics, and astronomy departments of Istanbul University and was also one of the first modern Turkish scholars to undertake research on the history of science in Turkey. After the death of his parents, his grandmother sent him to Dārüsşsafaka (school for orphans) when he was ten. After graduating first in his class in 1882, Salih Zeki was assigned to the Post and Telegraph Ministry (Administration). In 1884, the ministry decided to train expert cable engineers and physicists in Europe, and so he, along with several of his friends, was sent to Paris. After studying electrical engineering at the École Polytechnique in Paris, Salih Zeki returned to Istanbul in 1887 and started working at his former workplace as an electrical engineer and inspector. At the same time, he taught physics and chemistry at the Faculty of Political Sciences (1889–1900). He also served as the director of the observatory (1895) and as a member of the board of the Ministry of Education (1908). After the declaration of the Second Constitutional Government, Salih Zeki was appointed in 1910 as the principal of the Galatasaray High School. In 1912, he became Under Secretary of the Ministry of Education and in 1913 the president of Istanbul University. In 1917, he resigned as the president but continued to be a professor at the University in the Faculty of Sciences until his death.

Salih Zeki played an important role in the construction and administration of the new State Observatory (Rasadhane-i Amire), this approximately 300 years after the establishment of an observatory in Istanbul in 1575 by **Taqī al-Dīn.** With the support of the French government, an observatory was opened in Istanbul in 1868, whose purpose was to disseminate weather forecasts to other meteorological centers *via* cable. Aristide Coumbary (Coumbary Efendi), who had come to Turkey to develop the telegraph cable network, was appointed as the director. This observatory, which is the forerunner of today's Kandilli Observatory, sent Coumbary Efendi as the Ottoman delegate to the International Meteorological and Astronomical Congress that was held in Vienna in 1873; in accordance with decisions taken at the congress, official ties were established with other observatories in Europe. Every year, weather forecast summaries and reports on earthquakes that occurred in Ottoman territories were published based on the observations made at this observatory. Approximately ten meteorological stations were affiliated with this observatory when it was first established, and these stations reported their daily observations *via* cable to the observatory. The central office in Istanbul forwarded these observations, also *via* cable, to observatories in Paris, Berlin, Vienna, Saint Petersburg, and Hungary and received their reports in the same manner. At the same time, these data were entered on synoptic maps on a daily basis. The observatory council, comprising three persons, also undertook to determine time, longitudes and latitudes, and magnetic declination.

After Coumbary, Salih Zeki was appointed as the director of the observatory. After Salih Zeki's appointment as the president of Istanbul University, the observatory moved to Maçka, to the building facing the Artillery School. On 12 March 1909, during the Young Turk revolution, the observational equipment and seismographs at

Maçka were mostly destroyed. What was salvaged was later given to Kabatas High School. Now Under Secretary to the Ministry of Education, Salih Zeki recommended **Mehmed Fatin Gökmen**, one of the leading scientists at the time, to be director of the observatory. Assuming his duties in 1910, Gökmen was charged with establishing a new observatory; this was accomplished in 1911 with the building of the Kandilli Observatory, which is still in operation today.

Among Salih Zeki's main works in astronomy are a *New Cosmography* (Istanbul, 1915) and an *Abridged Cosmography* (Istanbul, 1916). He also wrote a basic physics textbook, *Hikmet-i Tabiiyye* (Istanbul, 1896), that explained the concepts of general and applied physics and was used as one of the basic textbooks in physics education in Turkey for many years. In history of science, he composed the *Asar-ı Bakiye,* which was written to extol the successes of Muslim scientists, particularly in the fields of mathematics and astronomy. It contains accounts of the historical development of mathematics, algebra, geometry, and astronomy. Salih Zeki wrote this five-volume book by using the works of Western historians of science such as J. E. Montucla, P. Tannery, and M. Cantor as well as original texts in the libraries of Istanbul. The first volume, which deals with plane and spherical geometry, and the second volume, which takes up algebra, were published in 1913/1914; however, his third, fourth, and fifth volumes, which deal with astronomy, were not published. His *Kamus-i Riyaziyat* (Dictionary of Mathematics), whose ostensible purpose was to provide a dictionary of terms for mathematics and astronomy, was also meant to introduce the biographies and works of mathematicians and astronomers. The first two volumes out of the 12 volumes of this work were published, but the other ten volumes remain in draft form. Finally, it is worth mentioning that Salih Zeki also wrote articles for a number of newspapers and magazines that introduced readers to scientific and history of science topics.

Hüseyin Gazi Topdemir

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Samarqandī: Shams al-Dīn Muḥammad ibn Ashraf al-Ḥusaynī al-Samarqandī

Born **Samarqand, (Uzbekistan)**
Died **1302**

Shams al-Dīn al-Samarqandī, who lived in the 13th century, wrote books on *kalām* (theology), logic, mathematics, and astronomy; his works were taught for many centuries in the *madrasas* (schools) throughout the Islamic world.

Little is known about his life. After studying the standard curriculum in the basic religious sciences, Samarqandī mastered *kalām*, (logic, and geometry). His works in these fields cover the standard material of Hellenistic and Islamic knowledge, but they also contain contributions that are original both in content and method. One of the most striking features of his works is that they set forth the idea of a universe based upon geometrical forms. In this sense, he can be regarded as the founder of the movement that might be named "geometrical" *kalām* in the Islamic world.

In the field of theoretical astronomy, Samarqandī wrote a (commentaroy) *sharḥ* on **Naṣīr al-Dīn al-Ṭūsī**'s *taḥrīr* (Recension) of **Ptolemy**'s *Almagest.* He also wrote a general astronomy book, no longer extant, reportedly entitled *al-Tadhkira fīʿilm al-hay'a.* Finally, he prepared the *ʿAmāl al-taqwīm li-'l-kawakīb al-thābita*, which was a star calendar for the year 1276–1277. Unfortunately, most of Samarqandī's astronomical works have not been studied yet.

Samarqandī was most influential for his various textbooks, which provided a wealth of information about the content and methods of past scholars and greatly influenced future generations, who studied these books in various *madrasas*. His geometrical work entitled *Ashkāl al-ta'sīs* contains 35 propositions from Euclid's *Elements*; the first 30 propositions are strictly geometrical, while the last five deal with what has been called "geometrical algebra." Regarding the problem of the fifth ("parallels") postulate, he supported Euclid and considered the criticisms of earlier Islamic mathematicians to have been misplaced. The most important aspect of the book was Samarqandī's view that a study of geometry was a propaedeutic to the study of the forms of Platonic philosophy. It was used as a "middle-level" textbook for Muslim scholars in the *madrasas*, later most often with **Qāḍīzāde**'s commentary. Samarqandī also wrote widely used textbooks in the fields of *kalām*, logic, rhetoric, and philosophy.

İhsan Fazlıoğlu

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Samaw'al: Abū Naṣr Samaw'al ibn Yaḥyā ibn ʿAbbās al-Maghribī al-Andalusī

Flourished **(Iraq), 12th century**
Died **Marāgha, (Iran), 1174/1175**

Samaw'al was an eminent mathematician, physician, and astronomer, who composed some 85 treatises, all in Arabic. He was from a cultivated Jewish family that was originally from the Maghrib or, according to some sources, from al-Andalus. His father migrated to Baghdad and settled there. The young Samaw'al studied Hebrew, mathematics, and medicine. He traveled in the Muslim east, eventually settling in Marāgha in northwestern Iran, which was then a major city. He spent the rest of his life there as a physician in service of Jahān Pahlawān (died: 1186) of a semi-independent minor dynasty, the Atābakān. There he converted to Islam and wrote a book against Judaism, which became very controversial.

His main astronomical work is *Kashf ʿawār al-munajjimīn wa-ghalaṭihim fī akthar al-aʿmāl wa-'l-aḥkām* (Exposure of the deficiencies of the astronomers and their errors in most of [their] operations and judgments), written in 1165/1166. This treatise is divided into 25 (chapters) *bābs*, each consisting of several (sections) *faṣl*s, in which he indicates the errors that he has found in the astronomical works of Greek scientists, such as Euclid, **Archimedes**, and **Apollonius**, of Islamic scientists such as **Ibrāhīm ibn Sinān**, **Abū Jaʿfar al-Khāzin**, **Bīrūnī**, **Abū Maʿshar**, **Ḥabash**, **Ṣūfī**, and **Ibn al-Haytham**, and of Indian scientists such as **Brahmagupta**. The titles of the chapters are as follows:

(l) The reason for composing this book;
(2) On finding altitudes by astrolabe;
(3) On finding altitudes by shadow;
(4) On sines;
(5) On observations;
(6) On calendars;
(7) On interpolation;
(8) On finding hour-angles from equal hours;
(9) On equation of time;
(10) On daily hours;
(11) On ascensions;
(12) On projection of rays;
(13) On latitudes of planets;
(14) On aphesis;
(15) On true horizons;
(16) On finding heights of mountains and other high objects;
(17) On positions of fixed stars;
(18) On the nature of planets;
(19) On animodars;
(20) On elections (of proper times);
(21) On oblique ascensions;
(22) On the times of conjunctions, syzygies, and transfers;
(23) On properties of inscribed polygons and their effects on the sublunar world;
(24) On syzygies of epicycles; and
(25) Types of indications.

In the last chapters (20–25), Samaw'al uses a type of philosophical argument based upon his previous chapters to explain his view regarding the effects of stars on terrestrial events. He concludes that because the stars are innumerable and the relations and effects among them are virtually incalculable, an astrologer would need to take into consideration 6,817 variables for each person, therefore making it impossible to predict the future in any meaningful way.

Samaw'al was perhaps best known for his work in mathematics, especially algebra and arithmetic. He also wrote on medicine.

Negar Naderi

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Sampson, Ralph Allen

Born **Schull, Co.Cork, Ireland, 25 June 1866**
Died **Bath, England, 7 November 1939**

British astronomer Ralph Sampson made his mark with an analysis of the dynamics of the interactions of the four large (Galilean) satellites of Jupiter. As Astronomer Royal for Scotland he also encouraged major instrumental innovations, including the development of the Shortt Free Pendulum Clock and the use of microphotometers.

Sampson was the fourth of five children of James Sampson from Cornwall and Sarah Anne (*née* Macdermott) Sampson, an Irishwoman of Huguenot descent. When he was five, the family moved to Liverpool, England, and suffered from deprivation when the father became ill and his investments in the Cornish tin mines failed. As a result, Sampson had little education until the age of 14, when he entered the Liverpool Institute. He won a scholarship to Saint John's College, Cambridge, where his tutor was **John Adams**, and he graduated as third wrangler in the mathematical *tripos* of 1888. Sampson then took up a lectureship in mathematics in King's College, London and in 1889 was awarded the first Smith's Prize and Fellowship of his college in Cambridge. He returned to Cambridge in 1890 and became the first holder of the newly established Isaac Newton Studentship in Astronomy and Physical Optics. Sampson worked for 2 years on astronomical spectroscopy with H. F. Newall and in 1893 published a paper "On the Rotation and Mechanical State of the Sun." This was a highly significant publication as it showed for the first time the importance of radiation compared to convection in the outward transport of heat generated in the Sun's interior.

In 1893, Sampson was appointed professor of mathematics in the Durham College of Science at Newcastle upon Tyne. Two years later, he moved to the chair of mathematics in Durham itself and became director of Durham Observatory. Sampson's interest in this observatory led to the installation of the Durham almucantar, an instrument in which transits of stars were observed across

a horizontal circle instead of a vertical wire in the meridian. The instrument attracted much interest, and it was used for some years for observations of the variation of latitude.

It was in Durham that Sampson undertook his greatest work, the dynamical theory of the four largest satellites of Jupiter. At that time, there were serious discrepancies between the theoretical predictions and actual observations of the four satellites. Sampson used a series of accurate observations from Harvard College Observatory to amend the existing theory of the satellite orbits, but the disagreement between theory and observation persisted. He worked out a new dynamical theory and published in 1910 *Tables of the Four Great Satellites of Jupiter*, giving the positions of the satellites from 1850 to 2000. His *Theory of the Four Great Satellites of Jupiter* appeared in 1921 and earned him the Gold Medal of the Royal Astronomical Society in 1928.

Quite a different task that Sampson worked on at Durham was the editing of the unpublished manuscripts of his old tutor, Adams, for Cambridge University Press. These were published as *The Scientific Papers of John Couch Adams*. Sampson's varied achievements were recognized by his election to the Royal Society in 1903.

In 1910, Sampson was appointed Astronomer Royal for Scotland and professor of astronomy in the University of Edinburgh. During his tenure of 27 years in Edinburgh, he made notable contributions in three main areas: the determination of time, the optical performance of telescopes, and objective methods for photometry and spectrophotometry of stars.

Sampson recognized that an observatory's clock was one of its most important instruments and deserved proper attention. At the Royal Observatory, he introduced a system for monitoring the performance of the clocks to an accuracy of one thousandth of a second. Sampson improved the temperature control of the clock chamber, and he installed radio equipment for comparing time signals from clocks in other institutions. His interest in clocks led to several substantial papers on the subject in the publications of the Royal Society of Edinburgh.

Among the clocks in the observatory was one better than all the others. It had been designed by a civil engineer, W. H. Shortt in association with the Synchronome Company. This Shortt free pendulum clock was so accurate that it could detect for the first time small irregularities in the rotation of the Earth. Shortt clocks were adopted as the standard timekeepers in many observatories until they were replaced by quartz clocks. Sampson's fundamental contributions to precise time determination were recognized by his election as the first president of the Commission de L'Heure, the international organization founded to study the problems of astronomical timekeeping.

When Sampson tried to bring into use an old 24-in. reflector at the Royal Observatory, an old interest in theoretical optics was revived. His studies of optical aberrations resulted in two papers in the *Philosophical Transactions of the Royal Society* (1913, 1914). In the latter of these, he suggested that the optical aberrations of a Cassegrain reflector could be reduced by inserting a pair of suitable lenses in the outgoing beam. Sampson suggested a similar approach for correcting the field of a Newtonian reflector. These innovative ideas were later developed by others to good effect.

In an effort to make some use of the 24-in. reflector where its poor image quality would not matter, Sampson decided in 1915 to use it for photoelectric photometry of stars using alkali metal detectors that had recently been developed in Germany. Most of the laboratory work to support this project was carried out by E. A. Baker. In 1920, the program was modified by replacing direct measurement of each star at the telescope by microphotometry of the densities of star images on photographic plates. This method was extended to scanning the spectra of stars, and the recording microphotometer became a standard instrument for stellar photometry.

Sampson applied the forgoing techniques to the analysis of objective prism spectra with a view to determining the spectral distribution of intensity of various types of stars. This led to estimates of stellar temperatures in a range of spectral types from B0 to M0. These results were published by the Royal Society of Edinburgh in 1925 and 1928.

Sampson's desire to renew the equipment of the Royal Observatory was frustrated by World War I and its aftermath. It was only in 1936 that a 36-in. reflector made by Grubb Parsons was installed in the East Dome, and a versatile Hilger spectrograph was added the following year. This new equipment allowed the spectrophotometric program to be extended to much fainter stars.

In 1937, failing health compelled Sampson to retire at the age of 71. He and his wife Ida (*née* Binney), whom he had married in 1894, settled in Bath. Sampson was survived by his wife, a son, and four daughters.

Sampson was deeply involved in the affairs of the Royal Society of Edinburgh, being a member of council for 20 years including some years as general secretary. He served as president of the Royal Astronomical Society of London from 1915 to 1917. Sampson was awarded the honorary degrees of Sc.D. from Durham and LLD from Glasgow. The International Astronomical Union named the lunar crater at 29°.7 N and 16°.5 W in his honor.

Ian Elliott

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Sanad ibn ˁAlī: Abū al-Ṭayyib Sanad ibn ˁAlī al-Yahūdī

Flourished **Baghdad, (Iraq), 9th century**

Sanad ibn ˁAlī was an active mathematician and astronomer in Baghdad during the 9th century and worked as an astrologer for Caliph **Ma'mūn**. Sanad was the son of a Jewish astrologer who worked in Baghdad and counted among his clients people from the ˁAbbāsid court. Sanad converted to Islam responding to the lure exercised by the caliph.

In his youth, Sanad studied by himself several scientific books, among them the *Almagest*. He tried to gain access to the illustrious circle of scholars around **ˁAbbās ibn Saˁīd al-Jawharī** (first half of the 9th century), who regularly met in his house to discuss the latest scholarly and social news. But being merely 20 years old at this time proved to be an obstacle. According to a story told by Aḥmad ibn Yūsuf ibn al-Dāya (died: *circa* 952) on the authority of Abū Kāmil Shujāˁibn Aslam (*circa* 850–*circa* 930), Sanad convinced Jawharī of his superior knowledge of the *Almagest*. As a result, Sanad was not only permitted to stay and take part in the talks of the illustrious circle, but Jawharī, who was a companion of the caliph, also introduced him to Ma'mūn and recommended him as a new, promising servant.

Sanad wrote four mathematical texts on algebra, Indian arithmetic, mental calculation, and Euclidean irrational quantities, the latter being one of the earliest commentaries on Book X of Euclid's *Elements*. He composed a *zīj* (astronomical handbook) and explained a method for determining the circumference of the Earth by observations of the Sun. There is also a report by **Bīrūnī** in his *The Determination of the Coordinates of Cities* (Ali, 1967, pp. 185–186) that Sanad had found the size of the Earth by measuring the dip of the horizon from the summit of a high mountain, a method later used to good effect by Bīrūnī himself; this had been done "in the company of Ma'mūn when he made his campaign against the Byzantines." His *zīj* is presumably lost, and thus it is unclear how it was related to the famous so called *al-Zīj al-mumtaḥan* (The verified *zīj*) produced by a group of astronomers from Ma'mūn's court.

Sanad built and headed an observatory behind the Bāb Shammāsiyya in Baghdad, collaborating there with a group of observers. According to an account of the Egyptian astronomer **Ibn Yūnus** of the astronomical excursions carried out by the court astronomers in Ma'mūn's lifetime, Sanad had himself written such an account in which he claimed to have participated in one of these expeditions. However, R. Mercier, and following him D. King, doubt the authenticity of both these claims.

Sonja Brentjes

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Sanford, Roscoe Frank

Born **Faribault, Minnesota, USA, 6 October 1883**
Died **Pasadena, California, USA, 4 April 1958**

American observational astronomer Roscoe Sanford was a firm, early supporter of the idea of "island universes" or spiral nebulae as independent stellar systems outside the Milky Way, based on data he had collected concerning their apparent sizes, brightnesses, and locations relative to the galactic plane.

Sanford received an A. B. from the University of Minnesota in 1905 and, after a year of high school teaching in Minnesota, came to Lick Observatory as an assistant to Richard H. Tucker. From 1908 to 1915, he was with Lick expeditions at San Luis, Argentina, determining positions of southern stars, and at Santiago, Chile, measuring radial velocities. Sanford returned to Lick in 1915 and completed a Ph.D. dissertation in 1917, working with **Heber Curtis**. The thesis used images of spiral nebulae, plus the idea (established in the earlier thesis of **Edward Fath**) that their spectra resemble spectra of star clusters, to conclude that they are separate galaxies, well outside the Milky Way. He attributed the absence of spirals near the galactic plane to absorption there. Much of the data used by Curtis in the 1920 Curtis–Shapley debate came from Sanford's thesis.

Sanford spent about a year at Dudley Observatory before joining the scientific staff at Mount Wilson Observatory in 1918, where he remained until his 1950 retirement. While at Mount Wilson, Sanford worked primarily on the composition and motion of carbon stars, making use of the high-resolution spectra that were possible only with the world's largest telescope. He was the first to notice the great strength of the 6707 Å line of lithium in T Tauri stars, which is a signature of their youth, and of older stars having fused all their lithium to other elements.

Virginia Trimble

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Santini, Giovanni-Sante-Gaspero

Born **Caprese Michelangelo, (Tuscany, Italy), 30 January 1787**
Died **Noventa Padovana near Padua, Italy, 26 June 1877**

Giovanni-Sante-Gaspero Santini was a professor, observatory director, and specialist in comet orbits. He was the third of 11 children of Gerolamo and Caterina Brizzi. His uncle, the priest Giovambattista Santini, taught him Latin, grammar, philosophy, and mathematics. In 1801, Santini entered the seminary of Prato to complete his education, and in 1802 enrolled in law at the University of Pisa. At the same time, he attended free courses in mathematics and physics. The university rector, Lorenzo Pignotti, and the politician Vittorino Fossombroni (both from Arezzo), to whom Santini's uncle had recommended him, employed him at the observatory of the Museum in Florence. To learn astronomy, he was sent to the Observatory of Brera in Milan, directed by **Barnaba Oriani**. There Santini learned how to observe and calculate orbits of minor planets from the astronomer **Francesco Carlini** while studying French, English, and German. In 1806, as a consequence of the changing political situation in Tuscany, Santini was appointed assistant astronomer under abbé Vincenzo Chiminello at the Observatory of Padua. The new Napoleonic government of the Veneto region had received Santini's excellent references supplied by professors Angelo Cesaris and Oriani. Santini found a tired and ill director in Chiminello, who had to work hard to save the *specola* during the events following the fall of the Republic of Venice. Santini started by updating the old and obsolete instruments. Then, in 1810, he purchased a transit instrument. In 1815, he calculated the precise latitude of Padua with his new Reichenbach repeating circle, and in 1822 he bought an equatorially mounted telescope.

In 1810, Santini had married Teresa Pastrovich, who died in 1843. The following year, he married Adriana Conforti, who outlived him, but, like Teresa Pastrovich, left him childless. Despite his two marriages, some biographical dictionaries call Santini "abbé," perhaps owing to the cassock he used to wear when in Pisa, or because he was confused with his uncle Giambattista.

In January 1813, Santini was appointed full professor of astronomy at the University of Padua. In 1817, after Chiminello's death, his chair was confirmed by the Austrian government, which had ruled Venice since November 1813. Santini was also appointed director of the observatory. In 1837, he installed a meridian circle, and in 1838 he started the observations that would lead him to make a star catalog of the Bessel zones between declinations +10° and −10°. Santini was able to carry out this long and laborious work with the aid of astronomer Virgilio Trettenero. After 10 years, the work was published as the *Cataloghi Padovani*, and was valued by the astronomical community for the precision of its stellar coordinates. Santini had undertaken such heavy work because he needed many comparison stars for orbit calculations. In the 1864 Encke–Galle catalog of cometary orbits, he was attributed the calculation of 17 orbits, among the many others he had published in other scientific journals. In particular, Santini calculated the orbit of the short-period comet 3D/Biela very precisely. This comet had been discovered in 1826, but was not recovered at its 1839 perihelion transit because its orbit had been greatly disturbed by the major planets, especially Jupiter. Its return in 1846 was seen thanks to Santini's exact ephemerides, calculated and published in 1842. Santini's works were well known throughout Europe, and the Observatory of Padua became famous among European ones for its research in theoretical and practical astronomy.

As astronomy professor, Santini published the two-volume treatise *Elementi di Astronomia* (1819/1820 and a 2nd edition in 1830). This work was extensively used by the famous astronomers Baron **János von Zach** and **Johann von Littrow**, and became a fundamental textbook for Italian students in the 19th century. In 1828, he published an optics treatise in two volumes (*Teorica degli Stromenti Ottici*), the only such book in Italy, which also became a milestone for students, and optical instrument makers, too. Santini taught astronomy and, as substitute professor, algebra and geometry, as well as infinitesimal calculus for nine and seven years respectively.

Santini was rector of the university in 1824/1825 and 1856/1857, and dean of the Faculty of Mathematics from 1845 to 1872. From 1866 to 1875, he was mayor of Noventa Padovana, a village near Padua where he spent the last years of his life.

Santini corresponded with many Italian and European astronomers, among whom are **George Airy, Giambattista Amici, Friedrich Argelander, Wilhelm von Biela, Francesco Carlini, John Herschel, Joseph** and **Karl von Littrow, Barnaba Oriani, Heinrich Schumacher**, Zach, **Friedrich Struve, Otto Struve**, and many others. He personally knew many of the astronomers who visited him in Padua such as John Herschel, Karl von Littrow, Otto and Wilhelm Struve, and Baron von Zach. Others he met in the autumn of 1843, during his journey across Germany with Roberto De Visiani, professor of botany and director of the Botanical Garden at the University of Padua.

Santini was a member of 21 Italian and foreign scientific societies, among which are the Academy of Padua; Royal Astronomical Society; Institut de France; Kaiserliche Akademie der Wissenschaften of Vienna; Istituto Veneto di Scienze, Lettere. ed Arti, *etc*. Nine orders of knighthood were bestowed upon him. Santini's works were published in many journals of the time.

Luisa Pigatto

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Śatānanda

Flourished **Ujjayinī, (Ujjain, Madhya Pradesh, India), 1099**

Śatānanda was an acclaimed Indian astronomer of the Hindu classical period (late 5th to 12th centuries). He was the son of Sañkara and Sarasvatī. Śatānanda was the author of an extremely popular astronomical manual, the *Bhāsvatī*, composed in 1099. In its eight short chapters, this work sets out the methodologies for preparing the daily almanac. But the author presents several variations from other texts of the same genre. He names his work after the word for the Sun, *bhāsvān*. In tune with his own name Śatānanda, meaning "delighting in hundreds," he uses the centesimal system for commencing the epochal position and specifies several multipliers and divisors in terms of hundreds. Again, unlike most manuals that are based on the more modern yet anonymous *Sūryasiddhānta* (10th or 11th century), he specifies that his work is drawn from the older *Sūryasiddhānta*, which had been condensed by astronomer **Varāhamihira** in his work, the *Pañcasiddhāntikā*.

Śatānanda also introduces several innovations to make the results computed by the *Bhāsvatī* more correct. For the computation of longitudes of the mean positions of planets, he uses not the *ahargaṇa* (number of elapsed days) but the *varṣagaṇa* (number of elapsed years). In specifying the beginning of the year, he uses the true *Meṣādi* (first point of Aries) and not the mean *Meṣādi* as in other texts. The positions of the Sun, Moon, and other planets are not stated in terms of *rāśis* (signs) but in terms of the *nakṣatras* (asterisms). He adopts the year 528 as the reference for precession measurements and the rate of precession as 1′ per year.

Śatānanda's work has given rise to a number of expository commentaries.

Ke Ve Sarma

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Saunder, Samuel Arthur

Born **London, England, 18 May 1852**
Died **Oxford, England, 8 December 1912**

English mathematician and amateur astronomer Samuel Saunder was a leading selenographer at the beginning of the 20th century and helped create both a standard system of lunar nomenclature and an accurate system of lunar coordinates. Educated at Cambridge University as a mathematician, Saunder spent his entire career as professor of mathematics at Wellington College, Berkshire.

However, Saunder's great passion was astronomy, especially the study of the Moon. Attracted to the problem of measuring the exact locations of the lunar features, Saunder used both a micrometer and photographic plates to determine the position of Möstig A, the Moon's fundamental point. His measurements – to within 0.1″ – were fifty times more accurate than those any previous observer had obtained. Saunder then measured positions for over 3,000 other central lunar formations relative to Möstig A.

After the invention of the telescope, the naming of lunar features became a source of confusion and great discord among astronomers. Saunder became acutely aware of this problem while measuring the 3,000 reference points and advocated an international committee to blend the various naming conventions that had been introduced over a three-year period. With the strong recommendations of the Royal Astronomical Society and the Royal Society, such a committee was formed in 1907 under the auspices of the International Association of Academies. Saunder was appointed to the committee and, along with **Julius Franz**, was given the task of constructing an accurate map, using the measurements that the both of them had made.

Unfortunately the deaths of both Saunder and Franz, along with the advent of World War I, prevented the successful conclusion of the project, and the committee collapsed. A successful resolution to the lunar nomenclature problem was not achieved until after the formation of the International Astronomical Union in 1919.

Leonard B. Abbey

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Saunders, Frederick Albert

Born **London, Ontario, Canada, 18 August 1875**
Died **South Hadley, Massachusetts, USA, 9 June 1963**

Canadian-American spectroscopist Frederick Saunders gave his name to a method, devised with **Henry Norris Russell**, called Russell–Saunders coupling, used to calculate how the electrons in atoms with more than one in the outer, active shell interact to produce the emission and absorption features. It is also called L–S coupling, where L and S are symbols for the orbital and spin angular momenta of the electron ensemble.

Saunders was the son of the eminent Canadian agriculturist, William Saunders, and Sarah Robinson, both of whom emigrated from England. He married Grace Elder in 1900; they had two children, Anthony E. and Margery (Middleton). He married Margaret Tucker in 1925.

Saunders was a physics student at the University of Toronto, taking his BA in 1895. A student of **Henry Rowland** at Johns Hopkins University, Saunders took his Ph.D. there in 1899. After a brief stay at Haverford College as physics instructor (1899–1901), he moved to Syracuse University (1901), becoming an associate professor (1903) and professor (1905).

In 1913/1914, Saunders ended his time at Syracuse with a year in Europe, working in Cambridge and in Tübingen, in the latter with Louis Paschen. Paschen was the 1908 discoverer of the first series of infrared lines of hydrogen (the Paschen series). With Ernst Back (1881–1959), Saunders studied the effect (now generally called the Paschen-Bach effect) on spectral features of magnetic fields stronger than those studied by **Pieter Zeeman**. From Paschen, Saunders learned the methods of laboratory spectroscopy, and he identified large numbers of lines with the atoms and ions responsible, especially among the alkali metals (lithium, sodium, potassium, *etc.*). While in Cambridge, he worked with **Alfred Fowler**.

From 1914 to 1918, Saunders served as professor of physics at Vassar College. He spent several months in Washington during 1918, in a group directed by **Robert Millikan**, for the National Research Council.

In 1919, Saunders joined the physics department at Harvard University at the invitation of Theodore Lyman, becoming associate professor in 1921 and professor in 1923. He retired as professor emeritus in 1941. During his retirement years, Saunders lectured at Mount Holyoke College.

Saunders's pioneering work with Russell concerned the spectra of the divalent alkaline metals (beryllium, magnesium, calcium, *etc.*). Each of these has two electrons in its outer, active shell, and Russell–Saunders coupling, which fits their spectra well, assumes that the orbital angular momenta and the spin angular momenta of the two electrons interact dominantly, with smaller interaction between the total spin and total orbital angular momenta. The opposite case, in which each electron sees primarily itself, is called jj coupling and is appropriate for elements like iron where the electrons are further from the nucleus. Saunders was elected to the National Academy of Sciences in 1925.

In later years, Saunders turned to acoustical research, particularly the acoustics of the violin. In 1930, he published a basic college textbook in physics that was widely used for about a decade.

Richard A. Jarrell

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Savary, Felix

Born **Paris, France, 4 October 1797**
Died **Estagel, Pyrénées-Orientales, France, 15 July 1841**

A student and then faculty member at the École Polytechnique, Felix Savary was the first to compute the orbit of a binary star in 1827, showing that the orbit is elliptical and, therefore, that **Isaac Newton**'s laws of gravity apply outside the Solar System.

The double star ξ Ursa Majoris is made up of bright components with a 60-year period; it was an ideal candidate for applying Newton's law of gravitation to the stars. **William Herschel** had discovered the pair (1780), and **Friedrich Struve** had more recently measured it, but it was Savary who just beat **John Herschel** in making the calculation (published in *Connaisance des Temps pour l'an 1830*).

Savary is better known to physicists as the colleague of André-Marie Ampère and to mathematicians for describing the geometrical figure known as the *roulette*.

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Savile, Henry

Born **Bradley, Yorkshire, England, 30 November 1549**
Died **Eton, Berkshire, England, 19 February 1622**

Henry Savile is known today primarily for his endowment of the Savilian Chair of Geometry and Chair of Astronomy at Oxford; in his day he was also noted for an Oxford series of lectures on the *Almagest*.

Savile, son of Henry and Elizabeth (*née* Ramsden) Savile, matriculated at Brasenose College, Oxford, *circa* 1561, and in 1565 he became a fellow of Merton College. Savile established his scholarly reputation in the 1570s with a brilliant series of lectures on the *Almagest*. The lectures are impressive in their use of ancient, medieval, and Renaissance sources – notably including **Nicolaus Copernicus** – to elucidate the text of **Ptolemy**'s classic work. Savile was ambivalent about the controversy over the Copernican theory. "Is it not all one," he famously replied to a colleague who asked about the movement of the Earth, "sitting at dinner whether my table be brought to me, or I goe [*sic*] to my table, so I eat my meat?" Nonetheless, his lectures did much to revitalize the teaching of mathematics in Oxford.

From 1578 to 1582, Savile toured the Continent, visiting a number of European astronomers and scholars. After returning from his travels, he was appointed Greek tutor to Elizabeth I. Handsome and eloquent, Savile proved to be a masterful courtier. His qualities won him academic preferments. In 1585, he was elected warden of Merton College, and 10 years later, despite considerable obstacles, he became provost of Eton while retaining his Merton post. Savile was an autocratic if effective administrator; under his leadership both Merton and Eton enjoyed an academic resurgence. Savile's own academic pursuits were as much historical and philological as they were astronomical. His later scholarship centered on ancient texts – The *Histories of Tacitus*, the works of Saint Chrysostom, and portions of the authorized version of the Bible. Yet he maintained a strong belief in the value of mathematical science, generously endowing the Savilian Chairs of Geometry and Chair of Astronomy at Oxford University in 1619. These professorships have been historically significant, having been held by **Christopher Wren**, **David Gregory**, **James Bradley, Charles Pritchard**, **Herbert Turner** (astronomy), and **Edmond Halley** (geometry) among others.

Keith Snedegar

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Sawyer Hogg, Helen Battles

Born **Lowell, Massachusetts, USA, 1 August 1905**
Died **Richmond Hill, Ontario, Canada, 28 January 1993**

American–Canadian astronomer Helen Sawyer Hogg for many years maintained the definitive catalog of variable stars in globular clusters, a task of considerable importance because these stars are keys to measuring astronomical distances and ages. Helen Sawyer was the daughter of Edward Everett Sawyer and Carrie Myra Sprague. She married **Frank Hogg** in 1930 and F. E.L. Priestly in 1985. The first marriage produced three children, Sally, David E. (a noted radio astronomer), and James.

Sawyer Hogg received an AB *magna cum laude* from Mount Holyoke College in 1926. She earned an AM in 1928 and a Ph.D. in 1931 from Radcliffe College, though her thesis work had been done with **Cecilia Payne-Gaposchkin** and **Harlow Shapley** at Harvard College Observatory, as Harvard did not at that time award science degrees to women. She, Frank Hogg, and Payne earned three of the first five astronomy Ph.D.s based on work at Harvard. Her early work with Shapley helped to establish both the direction and distance from the Sun to the center of the Milky Way Galaxy, both of which had been in dispute earlier in the century.

During this time Sawyer Hogg was an instructor at Smith College (1927) and at Mount Holyoke (1930/1931). When Frank Hogg obtained a post at the Dominion Astrophysical Observatory in 1931, the director, **John Plaskett** allowed Helen Hogg to observe with the 72-in. reflector. In 1935, the Hoggs moved to Toronto in anticipation of the opening of the David Dunlap Observatory [DDO]. At Toronto, Sawyer-Hogg was a research assistant until World War II. In 1940/1941, she was acting chair of astronomy at Mount Holyoke. With most of the male staff of the DDO in the military, Hogg began teaching in the University of Toronto Astronomy department (1941); she was later appointed assistant professor (1951), associate professor (1955), and professor (1957). Sawyer-Hogg was program director for astronomy for the National Science Foundation (1955/1956). She retired as professor emeritus in 1976.

Sawyer Hogg received the Annie J. Cannon Medal of the American Astronomical Society in 1950, the Rittenhouse Medal in 1967, the Royal Astronomical Society of Canada Service Award in 1967, the Dorothea Klumpke-Roberts Award from the Astronomical Society of the Pacific in 1983, and the Sandford Fleming Medal of the Royal Canadian Institute in 1985. A companion in the Order of Canada, she was also a Fellow of the Royal Society of Canada. Long active in the Royal Astronomical Society of Canada (president, 1957–1959; honorary president, 1977–1981), the American Association of Variable Star Observers (president, 1939–1941), the American Astronomical Society (councillor 1965–1968), and the International Astronomical Union, she also became the first president of the Canadian Astronomical Society (1971) and was a president of the Royal Canadian Institute (1964/1965). Sawyer Hogg held honorary degrees from Mount Holyoke and Waterloo, McMaster, Toronto, Saint Mary's, and Lethbridge universities.

Sawyer-Hogg was an international authority on variable stars in globular clusters. She published three catalogs of these objects in 1939, 1955, and 1973 and was the author of more than 200 papers. Sawyer-Hogg was also well known in Canada as a science popularizer – her syndicated column for the *Toronto Daily Star* was one of the most noteworthy Canadian science columns for 30 years. She later wrote a popular work, *The Stars belong to Everyone* (1976) and appeared on television programs. Sawyer Hogg continued to participate actively in astronomical conferences and share her knowledge with colleagues almost until the end of her life.

Richard A. Jarrell

Alternate name

Hogg, Helen Battles

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Schaeberle [Schäberle] John [Johann] Martin

Born **Oeschelbronn, (Baden-Württemberg, Germany), 10 January 1853**
Died **Ann Arbor, Michigan, USA, 17 September 1924**

German-American instrument-designer and observational astronomer John Schaeberle was one of the first astronomers at Lick Observatory and designer of the famed Schaeberle Camera. He was

the first to see the white-dwarf companion of Procyon in 1896, predicted by **Friedrich Bessel** in 1844.

Schaeberle's father, Anton Schäberle, a master saddle maker, and mother Christina Katherina Vögele, immigrated to Michigan in 1854 with their infant son. There his name changed to John Martin Schaeberle, and he was usually called Martin. Following his early education in Ann Arbor, he moved at age 15 to Chicago to serve an apprenticeship in a machine shop. There Schaeberle became interested in astronomy, and his mechanical skills enabled him to make mirrors for reflecting telescopes. The Great Chicago Fire in 1871 ended his apprenticeship. Returning to Ann Arbor, he completed high school in a few months and enrolled at the University of Michigan, where he studied engineering and mathematics, graduating in civil engineering in 1876.

Schäberle used telescopes of his own construction to make observations, first from the rooftop of his Chicago hotel, and after 1872, at a private observatory in Ann Arbor. Using a home-built 8-in. reflecting telescope, Schaeberle discovered comet C/1880 G1 from his private observatory. The following year, using the Henry Fitz comet-seeker at the University of Michigan's Detroit Observatory, he discovered comet C/1881 N1. As a student, Schaeberle's mathematical, mechanical, and observational skills caught the attention of **James Watson**, the observatory's director, and he soon became Watson's favorite pupil. After graduation, Schaeberle became Watson's assistant, and 2 years later, was promoted to instructor in astronomy, a position he held until 1888. The German astronomical methods, introduced at Michigan by Watson's teacher and predecessor **Franz Brünnow**, were well-suited to Schaeberle's interests and abilities. When Watson moved to the Washburn Observatory in 1878, Mark W. Harrington took his place. Harrington's primary interest was in meteorology, and so Schaeberle had responsibility for the bulk of the astronomical work of the Detroit Observatory during Harrington's tenure.

In 1888, Schaeberle became one of the inaugural astronomers at the new Lick Observatory, where he remained for 10 years. There he had responsibility for observations with the Repsold meridian circle.

The total solar eclipse of January 1889, which crossed northern California, captured Schaeberle's attention and prompted him to venture to Cayenne, French Guiana, to observe the next eclipse in December 1889. His desire to formulate a mechanical theory of the solar corona (as opposed to the prevailing magnetic theories) prompted him to devise a long-focus camera that could take photographs of the Sun. He designed a photographic telescope of 40-ft. focal length, driven by clockwork, which was portable, so could easily be taken on expeditions. The Schaeberle camera produced the best photographs of the solar corona ever produced, one of which revealed a comet in close proximity to the Sun that would not otherwise have been detected. Schaeberle took his camera to Mina Bronces, Chile, in 1893 and to Akkeshi, Japan, in 1896 to observe eclipses. He organized the expeditions on his own and recruited and trained civilians on location to assist him. The Schaeberle camera continued to be used by astronomers on expeditions at locations around the world, until 1932 when **Heber Curtis** took the last coronal plates at Fryeburg, Maine, USA.

Schaeberle's persistent visual observations led to his discovery in 1896 of the 13th-magnitude companion of Procyon, using the 36-in. Lick refractor. It was only the second white dwarf to be observed (after Sirius B by **Alvan Clark**).

When **Edward Holden** resigned as director of Lick Observatory in 1897, Schaeberle was the natural choice to be acting director, a position he held until 1898 when the Lick Trustees made a political move and appointed **James Keeler** as director. Schaeberle could not accept this perceived injustice, so he returned to Ann Arbor.

Although he held no formal appointment, Schaeberle carried on his astronomical work from an observatory he built at his residence. He constructed a 24-in. telescope with a 3-ft. focal length, mounted equatorially, that he planned to equip with a modified bolometer to detect far infrared radiation from the Sun and stars. Unfortunately, the mirror broke while he was drilling a hole to modify the telescope. Half of the discarded mirror was later retrieved in the 1930s by astronomers at the University of Michigan and used as an off-axis parabola for infrared spectrometry.

Schaeberle never married. He was a founding member and first secretary of the Astronomical Society of the Pacific. He was awarded honorary degrees by the universities of Michigan (1893) and California (1898). The Astronomical Society of the Pacific awarded him a medal for discovery of his third comet on 16 April 1893. Over the course of his career, Schaeberle published more than 100 articles in scientific journals, some of which contained ingenious methods for determining instrumental constants. A lunar crater is named for Schaeberle.

Patricia S. Whitesell

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Schalén, Carl Adam Wilhelm

Born **Sweden, 11 January 1902**
Died **Sweden, 11 December 1993**

Carl Schalén discovered, independently of **Robert Trumpler**, the general interstellar absorption, but his contribution to this field has been nearly forgotten. He was the son of Claës Adam Schalén and Vivica Ebpa Charlotta Strokirk and, in 1940, married Agnes Carmen Elisabeth Rosenblad.

Schalén received his Ph.D. in astronomy at Uppsala University in 1929 as one of the students of **Östen Bergstrand** and a contemporary of **Bertil Lindblad** and **Knut Lundmark**. Schalén held the position of observator at Uppsala from 1941 to 1955 and was professor of astronomy at Lund University from 1955 until his retirement in 1968. He was elected to the Royal Academy of Sciences, Stockholm, in 1949 and was a member of the council of the European Southern Observatory very early in its history.

Schalén was a member of the group of astronomers at Uppsala University, centered around Bergstrand and Lindblad, which used stellar spectra to determine the distances to large numbers of stars. Luminosity criteria had been found that made it possible to determine the approximate distance to a star from knowledge of certain spectral details. In a series of early works, Schalén determined distances and other data for stars with the spectroscopic techniques developed by Lindblad.

Schalén early on took up an interest in the question of interstellar absorption. Is there general absorption of light as it travels through space, or is interstellar space totally transparent? The existence of localized clouds of obscuring matter had been known earlier; Schalén wanted to look for general absorption. In a paper published in 1929, he announced his finding that there is a general absorption in space that amounts to 0.5 magnitudes per kiloparsec.

These results came at about the same time as other astronomers found similar results. Trumpler at the Lick Observatory published a study in 1930 with a result that was almost identical to Schalén's. (The Schalén archive shows that he pointed out his earlier result to Trumpler, who replied that he did not know of the result when he wrote the 1930 paper.) Schalén also studied the properties of interstellar matter theoretically. He started using the theory of Gustav Mie in the early 1930s for studies of how light diffused as it passed through interstellar matter.

Carl Schalén's papers are at the Lund University library.

Gustav Holmberg

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Schall von Bell, Johann Adam

Born **Cologne, (Germany), 1591**
Died **China, 15 August 1666**

Johann Schall von Bell was a Jesuit missionary and astronomer in China who oversaw significant improvements in the Chinese calendar. He entered the Jesuits in 1511 and wxas determined to serve in the China mission. Schall von Bell arrived in Macao in 1619 where he studied Chinese for a few years awaiting permission to enter China, which at that time strongly opposed all foreigners, especially foreign teachers. Permission was granted, however, a few years later in an unusual way after a military attack by the Dutch Calvinists on the Portuguese Catholic settlement. He and other Jesuits helped the Portuguese quell the invasion and, when the story of their victory reached the emperor, he asked the Portuguese to help him fend off the Tartars from the north. In particular he wanted more Jesuits. Thus was Schall von Bell admitted into China; and he then made his way to Beijing, arriving when a minister hostile to Christians was being dismissed. He then took the Chinese name of Tang-Jo-Wang.

Schall von Bell was very energetic and a man of charm and self-confidence. He soon became an intimate friend of some important Chinese scientists who were quite impressed by his learning and his familiarity with astronomy. It was due to these gifts that Schall von Bell and his brother Jesuits were successful in conversing with educated Chinese about religion.

Schall von Bell was given responsibility for the calendar, which was especially important in Chinese culture – in fact, the prestige of the emperor was connected to the authenticity of the court calendar. On one occasion, Schall von Bell and his Jesuit companions were able to predict a solar eclipse that took place on 21 June 1629 more accurately than their Chinese rivals. That success opened the way for them to devote themselves with full energy to the task of calendar reform. At the same time, they were able to produce maps, astrolabes, and other scientific instruments with such effectiveness that these Europeans were eventually invited to establish an observatory within the royal palace. In 1639, the emperor expressed his esteem for Schall von Bell and his Jesuit coworkers when a procession of palace royalty arrived at the Jesuit residence.

Upon the death of the emperor in 1644, a successor was named who appointed Schall von Bell director of the national "Board of Astronomers." He later made him a mandarin, and showered the Jesuit with many favors. In 1661, the latter emperor fell seriously ill and died; he was succeeded by his son, Kang-h'si. In the palace, however, Schall von Bell's position was steadily being undermined because of the jealousy of some royal scientists. Their leader, Yang-Kuan, succeeded in having him and the Jesuits accused of high treason, and of teaching a superstitious religion. This was followed by imprisonment and a trial that resulted in the Jesuits being sentenced to a slow death. But on the day of sentencing, an earthquake intervened, followed by a great fire in the palace, which alarmed the superstitious judges and resulted in the Jesuits being set free.

Schall von Bell died after spending 47 years in China. Soon after his death, the record was righted. The emperor dismissed Yang Kuan and appointed another Jesuit, Father **Ferdinand Verbiest**, as his successor. The emperor restored all Father Schall's honors posthumously, and erected a monument at his grave that read "You leave us your undying fame and the glory of your name." Schall von Bell's tomb as well as those of fellow Jesuits, **Matteo Ricci** and Verbiest, were restored after the Cultural Revolution of this past century and were relocated on the grounds of a Communist training school. These tombs still can be visited today. Another memorial of Schall von Bell is a student hostel, named in his honor, on the campus of the Chinese University of Hong Kong.

Schall von Bell's *Trigonometria* and many other works were written and published in China. He constructed a double stellar hemisphere to illustrate planetary movement and wrote 150 treatises in Chinese on the calendar.

Joseph F. MacDonnell

Alternate name

Tang-Jo-Wang

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Scheiner, Christoph

Born **Wald (Markt Wald near Mindelheim, Bavaria, Germany), 25 July 1573**
Died **Neisse (Nysa, Poland), 18 June 1650**

Christoph Scheiner was a German mathematician, physicist, and astronomer, who was one of the first to observe sunspots.

After attending the Jesuit Latin school in Augsburg and the Jesuit college at Landsberg, Scheiner entered the Jesuit order in 1593. (In 1617, he was ordained a priest.) From 1598 to 1601, he studied mathematics and metaphysics at the university at Ingolstadt; then he worked (1602–1605) as a teacher of Latin at the Jesuit college in Dillingen. From 1605 to 1609, Scheiner studied theology in Ingolstadt. During 1610–1617, he was professor of mathematics (astronomy) and Hebrew at the university at Ingolstadt, from 1619 to 1620 professor in Innsbruck, and during 1620–1621 professor in Freiburg. In 1621, Scheiner became father confessor of Archduke Karl of Austria and Bishop of Neisse, and in 1622 he founded a Jesuit college in Neisse, and became its superior. From 1624 to 1633, Scheiner was in Rome on behalf of the college. (No details are known about this stay – perhaps there was diplomatic business.) Later he was in Vienna, and in 1636 he returned to Neisse, without resuming the post of principal of the college.

Scheiner's time was the beginning of modern scientific thinking, using experiment and observation, and the period when astronomy was influenced by the ideas of **Nicolaus Copernicus**. Scheiner, first of all, is famous for his discovery of sunspots in 1611. The telescope had been invented, and Scheiner was among the first to use it for astronomical observations. (He produced a telescope specifically for solar observations – the helioscope.) A "stained sun" was in conflict with conservative Christian doctrine, and therefore the Jesuit Scheiner had to be cautious. Thus in 1612, he communicated his observations in three letters written under the pseudonym "Apelles." As a result, a priority dispute with **Galileo Galilei** arose. (Nowadays we know that there were sunspot observations already before Scheiner and Galilei, but all seem to be independent of each other.) During his time in Rome, Scheiner wrote his main work, *Rosa Ursina sive Sol*, where he summed up all his knowledge on sunspots and other solar phenomena. He showed that Galilei made errors of observation, but although he came near to a modern understanding of the nature of sunspots, he followed the Christian doctrine in his book. If Scheiner had an influence on the Galilei prosecution, as sometimes is said, it is not proved.

Another memorable contribution of Scheiner is the invention of the panthograph (around 1603/1605, but published only in 1631), an instrument for copying plans on any scale. He also dealt with the physiological optics of the eye, and he published his results in his book *Oculus* … in 1619 (and further results also in *Rosa Ursina*). He stated that the retina is the crucial part for the sense of viewing, and he described the function of other parts including the pupil and iris. During his last years, Scheiner wrote a refutation of the Copernican theory, which was published posthumously, but had no influence at all.

Horst Kant

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Scheiner, Julius

Born **Cologne, (Germany), 25 November 1858**
Died **Potsdam, Germany, 20 December, 1913**

Julius Scheiner, along with **Hermann Vogel**, made the first determination of the orbit of an eclipsing binary star (Algol) from photographic observations of its radial velocities (1889), thus confirming the eclipsing hypothesis of that star's light variations. Scheiner's career spanned the late-19th-century transformation of astronomy from its emphasis on positional data and orbital motions to the newly emerging science of observational astrophysics. He made significant contributions to both areas of specialization and trained notable practitioners in the latter.

Scheiner was the son of Jacob Scheiner, a painter of architectural subjects and landscapes. His secondary education was completed at the Realgymnasium in Cologne. He was admitted to the University of Bonn in 1878 and was drawn toward astronomy by visits to its observatory, then directed by **Eduard Schönfeld**. Appointed an assistant at the observatory, Scheiner received his Ph.D. in 1882, for a study of the brightness variations of Algol. He acquired strong experimental and technical skills that were to serve him throughout his scientific career. Scheiner was married and the father of three children.

In 1887, Scheiner was appointed an assistant at the Royal Astrophysical Observatory in Potsdam; he was later named observer (1894) and senior observer (1900). There, he began a program of research on stellar radial velocities, under the direction of Vogel. Concurrently, Scheiner was made extraordinary professor of astrophysics at the University of Berlin and trained a number of researchers, including future Yerkes Observatory director **Edwin Frost**, in the newer spectroscopic methods.

By measuring the intensity of starlight across various wavelengths of its spectrum, the principle of spectrophotometry was born. As early as 1890, Scheiner was among the first to recognize that the so called color index of a star yielded an approximate measure of its surface temperature. In collaboration with **Johannes Wilsing**, Scheiner derived temperature estimates for over 100 stars by the spectrophotometric technique, thereby aiding Vogel's system of stellar spectral classification. Wilsing and Scheiner also made one of the earliest, though unsuccessful, attempts to detect radio waves from the Sun (1896). Other astrophysical investigations were Scheiner's measurements of the effective temperature of the Sun's surface (conducted with a pyrheliometer), his visual study of the intensities of three emission lines in the spectra of gaseous nebulae, and his record of the first absorption lines visible in a spectrogram of the Andromeda Galaxy (1899), which offered important clues to the true nature of this object.

As Vogel's health declined, Scheiner assumed more of the scientific and administrative work of the Potsdam Observatory. He represented that institution at three Astrographic Congresses (1891, 1896, and 1900) convened at Paris in conjunction with the international *Carte du Ciel* project. Between 1889 and 1912, Scheiner compiled six volumes of stellar positions, embracing more than 123,000 stars, in the Potsdam zone between +31° and +40° declination. Other projects that reflected the older style of positional astronomy were Scheiner's triangulation of more than 300 stars and 100 definable points within the Orion Nebula (from which future observers could derive the motions of these components). He also published a catalog of more than 1,500 double stars and tabulated data on their frequencies of occurrence.

In addition to teaching and research, Scheiner was a noted textbook author and popularizer, whose works strongly reflected his own research contributions. Two scholarly works, *Die Spectralanalyse der Gestirne* (The spectral analysis of the stars, 1890) and *Die Photographie der Gestirne* (The photography of the stars, 1897), were complemented by his *Populäre Astrophysik* (Popular astrophysics, 1908; 2nd ed., 1912).

Jordan D. Marché, II

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Scheuchzer, Johann Jakob

Born **Zürich, Switzerland, 2 August 1672**
Died **Zürich, Switzerland, 23 June 1733**

Johann Scheuchzer was a Swiss physician and natural philosopher, who provided one of the first descriptions of the Perseid meteor shower. He was the son of Johann Scheuchzer, the senior town

physician and calendar maker of Zürich. At first Scheuchzer attended the German, and then the Latin school, and subsequently the Zürich (Carolinum) Gymnasium. In 1692, Scheuchzer began studying natural philosophy at the University at Altdorf, near Nuremberg, Germany. A year later, he made his way to Utrecht the Netherlands and gained his medical doctorate there in 1694. During a subsequent stay at Altdorf, Scheuchzer studied mathematics and astronomy under **Georg Eimmart**, occupied himself with botany and anatomy, and collected fossils. After the death of Johann Jakob Wagner (14 December 1695), he was recalled as junior town doctor (or *Poliater*) to Zürich, and as candidate for professor of mathematics at the Carolinum. In 1697, Scheuchzer was elected to the Leopoldina, the Deutsche Akademie der Naturforscher (the German Academy of Naturalists). In the same year he married Susanna, daughter of Kaspar Vogel, a councillor and innkeeper. Further memberships followed (London, Berlin, and Bologna). In 1710, Scheuchzer became professor of mathematics at the Carolinium as well as a canon.

Influenced by John Woodward, Scheuchzer was an advocate of the Neptunist theory. He maintained that the giant salamanders and the vertebrae of saurians that he discovered were the remains of predeluge humans. Between 1702 and 1711, Scheuchzer undertook nine major journeys, during which he thoroughly investigated the natural history of Switzerland. His major works include the classic *Natural History of Switzerland* in Latin with Volumes 1–3 appearing in German in the period 1706–1708. By publishing his *Herbarium diluvianum* (in 1709), one of the first books to contain illustrations of fossil plants, he became one of the founders of palaeobotany.

In 1704, following election to the Royal Society of London, Scheuchzer sent his work for publication in the *Philosophical Transactions* – in 1706, his observation of the total solar eclipse of 12 May and in 1707, his observation of the lunar eclipse of 1706. In a drawing of the extremely high number of shooting stars that he observed on 8 August 1709, Scheuchzer depicted one of the earliest-known accounts of the Perseid meteor shower. His large map of Switzerland that appeared in 1712 was partially based on his own astronomical observations.

In the case of the book *Jobi physica sacra, oder Hiobs Natur-Wissenschaft verglichen mit der heutigen Ideen* (*Jobi physica sacra,* or The natural sciences of the Book of Job, compared with modern-day ideas.) (Zürich, 1721), the censor refused permission to print, unless Scheuchzer removed Copernican teachings and other objectionable material. Scheuchzer had to fall into line. Despite strong resistance by Zürich orthodoxy, he was eventually freely able to advocate the Copernican worldview in his *Kupferbibel*, the *Physica sacra* (1731–1735). In it, Scheuchzer discusses the *eclipsis passionalis*, the eclipse at Christ's Crucifixion, which is described by the Evangelists Matthew, Mark, and Luke, but which is an eclipse that cannot be explained as a natural event. This eclipse cannot have occured as a result of the natural laws of motion, but could only have taken place through God causing them to be violated. Scheuchzer invites comparison between a modern, mechanistic view of the Universe, based on Cartesian ideas, and the revealed truth of the Bible. For him, science serves to clarify when something must be a miracle.

Thomas Klöti
Translated by: *Storm Dunlop*

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Schiaparelli, Giovanni Virginio

Born **Savigliano, (Piedmont, Italy), 14 March 1835**
Died **Milan, Italy, 4 July 1910**

Giovanni Schiaparelli was one of the most widely known astronomical observers of the middle to late 19th century, in no small part due to his observations of Mars and their reputed canals. Born to wealthy parents, he was enrolled at age seven in the Gymnasium Lycée of Savigliano. After graduating from the gymnasium in 1850, Schiaparelli entered the University of Turin, where he excelled in applied mathematics. He graduated with honors in August 1854 with a degree in hydraulic engineering and civil architecture. Schiaparelli married Maria Comotti in 1865, and together they parented five children.

Upon leaving the University at Turin, Schiaparelli began teaching mathematics as a private tutor. In 1856, he moved to Berlin to

study astronomy under the guidance of **Johann Encke**. In 1859, Schiaparelli moved yet again, this time to the Pulkovo Observatory, where he studied with **Otto Wilhelm Struve** and **Friedrich Winnecke**. In July 1860, Schiaparelli was appointed to the position of second astronomer under **Francesco Carlini** at Brera Observatory in Milan. Upon Carlini's death, in 1862, Schiaparelli was promoted to director, a post he held until his retirement in 1900. From 1863 to 1872, Schiaparelli also held a professorship at the Royal Technical Institute at Milan, where he taught classes on astronomy, geodesy, and celestial mechanics.

During his tenure at the Milan Observatory, Schiaparelli initiated several productive observational programs. In 1861, he discovered the minor planet (69) Hesperia. With the appearance of a bright comet in 1862 (now recognized as comet 109P/Swift–Tuttle), his attention was turned toward these transitory objects, leading in 1866 to his most important enduring contribution to astronomy. In a series of letters to Father **Angelo Secchi**, Schiaparelli revealed a direct orbital coincidence between comet 109P/1862 O1 and the meteoroids encountered during the annual August meteor shower (the Perseids). His announcement was the first clear demonstration that meteors derive from comets. Schiaparelli outlined his ideas on the origin of comets and meteoroid streams in *Entwurf einer astronomischen Theorie der Sternschnuppen*. While correctly identifying meteoroids as the decay products of comets, Schiaparelli argued, wrongly as it turned out, that all comets and meteoroid streams were captured by the Sun from interstellar space.

In 1877, Schiaparelli began a series of studies of Mars, then at opposition. From these studies, he produced surface albedo maps and suggested that certain features were indicative of the planet having "seas" and "continents." Schiaparelli also believed that he saw linear features or *canali* on the planet's surface. The ambiguity of *canali*, meaning either channels or canals, left open the possibilities of their being either natural features on the Martian landscape or artificial constructions. In the event, Schiaparelli continued to observe Mars at each favorable opposition until 1890.

The apparent observation of "canals" on Mars remained a topic of great interest and controversy into the 20th century. American **Percival Lowell** championed the idea that the "canals" were, in fact, signs of intelligent life existing on Mars, but by 1915, when observations with larger telescopes than Lowell's failed to record the canals, their reality began to be doubted. His defense was that only a visual observer, taking advantage of brief moments of excellent seeing, can record the finest detail present on the martian surface. Modern observations, confirm on the one hand, that visual observers under very good skies will see more or less what Lowell and Schiaparelli saw, but, on the other hand, that there are no truly contiguous canal-like features.

While at the Milan Observatory, Schiaparelli also conducted a series of observations of Saturn, Venus, and Mercury. Between 1877 and 1878, Schiaparelli observed Venus with the aim of deducing its spin period. In contrast to all other observers at that time, Schiaparelli concluded that Venus was a very slow rotator, arguing that its spin period was somewhere between 6 and 9 months, with synchronous rotation being the most likely value (corresponding to a rotation rate of 224.7 days). Schiaparelli also concluded that Venus's spin axis was orientated perpendicularly to its orbit. Modern-day radar telescope studies of Venus have revealed that the planet in fact spins even more slowly than the synchronous rate (its spin period being 243.02 days), and that the planet spins in a retrograde sense, with the spin axis being inclined by 177° to its orbit. From observations of Mercury from 1881 to 1889, Schiaparelli concluded that it was in synchronous rotation around the Sun. This observation was generally accepted until radar measurements revealed in the mid-1950s that the spin-to-orbital-period ratio is not unity, as proposed by Schiaparelli, but actually 3/2. Between 1875 and 1900, Schiaparelli also made a series of observations of double stars.

Upon his retirement from the Milan Observatory in 1900, Schiaparelli devoted himself to the study of Babylonian and Biblical astronomy. In preparation for his theological and historical works, Schiaparelli read original texts in Hebrew, Assyrian, Greek, and Latin. His studies yielded a book on the astronomy of the Old Testament, along with a paper on the astronomical allusions contained in the book of Job. At the time of his death, Schiaparelli was working on a comprehensive review of the history of ancient astronomy; this monumental work was eventually prepared for publication, in three volumes, by his pupil Luigi Gabba in 1925.

Schiaparelli received many prestigious awards in his lifetime. The Royal Astronomical Society granted him its Gold Medal in 1872 for his work on cometary and meteoroid stream orbits. The Astronomical Society of the Pacific bestowed its highest honor, the Bruce Medal, upon him in 1902. He was also elected a fellow of the Royal Academy of Science in Turin, the Royal Astronomical Society, the Royal Society, and both the French and Viennese academies of science. In 1889, Schiaparelli became a senator of the Kingdom of Italy. Lunar, mercurian, and martian geographic features have been named in his honor, as was a minor planet (4062).

Martin Beech

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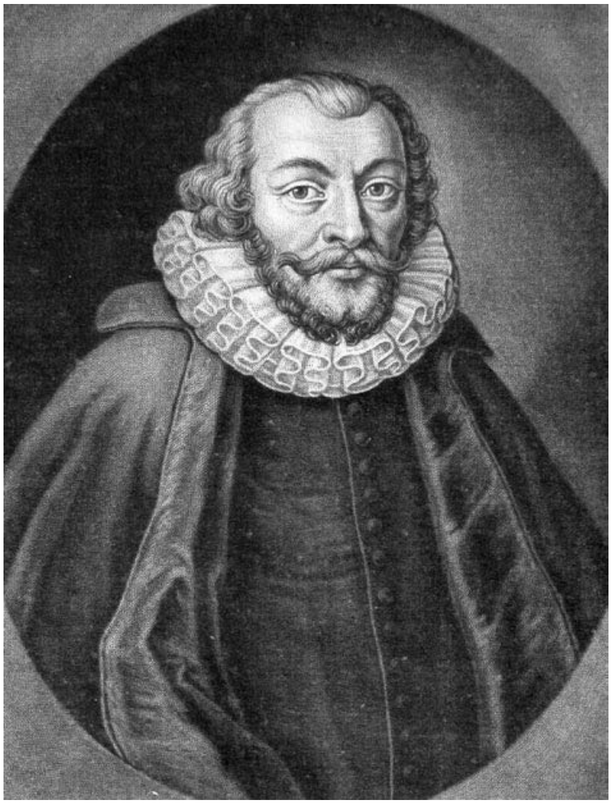
Sheehan, William (1988). *Planets and Perception: Telescopic Views and Interpretations, 1609–1909*. Tucson: University of Arizona Press. (The debate concerning the apparent observation of Martian canals has been thoroughly reviewed herein.)



Schickard, Wilhelm

Born **Herrenberg, (Baden-Württemberg, Germany), 22 April 1592**
Died **Tübingen, (Baden-Württemberg, Germany), 23 October 1635**

Wilhelm Schickard invented the first mechanical computer in 1623 to solve problems that arose in predicting planetary positions. His research included mathematics, cartography, and geodesy as well as astronomy.

Son of Lukas Schickard, he was born in a family of master joiners, builders, and vicars. Schickard was educated at the well-known Tübinger Stift and the University of Tübingen. After receiving his BA in 1609, and MA in 1611, he continued to study primarily theology and oriental languages until 1613. He surely received his education in mathematics, physics, and astronomy from **Michael Mästlin**, professor of mathematics and astronomy in Tübingen from 1584 to 1631. In 1613, Schickard became a Lutheran minister at several towns around Tübingen, and in 1619, he was appointed professor of Hebrew at Tübingen University, teaching biblical languages such as Hebrew and Aramaic. His textbook in Hebrew, *Horologium Hebraeum* of 1623, went into some 45 editions, it being his most popular book.

In 1617, Schickard first met **Johannes Kepler**, who also had studied theology in Tübingen and astronomy under Mästlin. Kepler commissioned Schickard to engrave the woodcuts and copper plates for the second part of his *Epitome* and the *Harmonice mundi* of 1618–1619. They remained friends – there exist 20 letters of Schickard addressed to Kepler, and 14 from Kepler. Upon the death of Mästlin in 1631, Schickard was appointed as professor of astronomy (in addition to his Hebrew appointment). In fact, he assisted Mästlin in his lectures from 1620, and also taught mathematics and geodesy from 1631. Schickard corresponded with many scientists including Matthias Bernegger, **Pierre Gassendi**, Daniel Mögling, **Ismaël Boulliau**, and **Maarten van den Hove**.

Schickard's first astronomical work was his paper of 1619 on his observations of the three spectacular comets of 1618 (C/1618 Q1, C/1618 V1, and C/1618 W1). There followed in 1624 his fundamental, 320-page monograph on the meteor of November 1623. He showed that meteoric studies can be as scientific as those of comets by **Tycho Brahe** and Mästlin. He was also a skilled mechanic and engraver in wood and copper plate.

Schickard's work of 1632/1633 on the transits of Mercury from 1627 on, his observational instruments having a mean error of 1′ 21″, are indeed remarkable. When he took over Mästlin's astronomical lectures in 1632, he gave out his own lectures in two parts – the theoretical part two was based on his *Picta Mathesis*, which is a remarkable attempt to present the full Copernican theory on the motion of the planets in a purely graphical way, using ruler and compass. The strength of it lies in Schickard's deep knowledge of spherical trigonometry (working out the necessary formulae in a didactic, clear way) and its graphical representation by means of descriptive geometry and stereographic projection – in fact, he tested all projection methods. Its secret was his methodical and systematic approach, the astronomy and not the mathematical theory being its goal. However, it forced him to use a purely Copernican approach. Schickard could not make use of the new astronomical laws introduced by his friend Kepler for elliptical orbits.

Schickard's brilliant achievements in the demanding area of the theory of the Moon – his prints and drawings are dated between 1624 and 1632 – reveal his full knowledge of the earlier work of **Ptolemy**, **Al-Battani**, **Al-Fargani**, **Nicolaus Copernicus**, Brahe, and **Christian Severin** (Longomontanus). His outstanding work concerning the theory of the Moon remained unfinished when he died of pestilence brought in by the Thirty Years War. The marginalia of Schickard's annotated copy of Copernicus' *De revolutionibus* are remarkable. They again reveal his skill, wide-ranging knowledge about this celestial science, and his standing as an astronomer.

Schickard is now best known for the invention in 1623 of the first mechanical computer capable of carrying out the four arithmetic operations; Pascal's arithmetic machine came later in 1642. Schickard's machine is known from his letters to Kepler, suggesting a mechanical means to help him with his logarithmic calculations of ephemerides. Unfortunately, no original copies of this calculator exist, but a working model was constructed by B. von Freytag Löringhoff from written documents in Tübingen in 1960. Schickard's calculator is a curious and striking conception (similar to **Leonardo da Vinci**'s imaginative inventions). Its capabilities, rediscovered after its reconstruction, have shown that it was indeed of practical use, though with the flaws inherent in its design.

Schickard, an expert mechanic, constructed additional scientific instruments. His *tellurium*, the first portable Copernican planetarium (reconstructed in 1977), could be used for the demonstration of the geocentric as well as the heliocentric system. His *rota hebraea* of 1621 was a device for the automation of Hebrew verb inflection. He was the first to apply the 1617 triangulation method of **Willebrord Snel** in 1624–1629 to geodesy, in particular in his surveying of Württemberg. Since systematic research concerning Schickard's *oeuvre* began only in 1957, no critical edition of any of Schickard's works has as yet appeared.

Paul L. Butzer

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Schiller, Julius

Born **Augsburg, (Bavaria, Germany)**
Died **Augsburg, (Bavaria, Germany), 1627**

Little is known about Julius Schiller; he is famous for his contribution to celestial cartography, thanks to his atlas entitled *Coelum Stellatum Christianum* (Augsburg, 1627). In this work, he improved **Johann Bayer**'s *Uranometria*, on the basis of **Johannes Kepler**'s *Tabulae Rudolphinae*, both correcting stars' positions and adding stars that Bayer omitted in his atlas.

The most interesting peculiarity of Schiller's atlas, from the point of view of the history of celestial cartography, was the attempt to substitute for the constellations deriving from the ancient tradition, new Christian asterisms inspired by the Old Testament (in the Southern Celestial Hemisphere) and the New Testament (in the Northern Celestial Hemisphere). The 12 zodiacal constellations were replaced with the figures of the 12 apostles. However, Schiller's proposal was not followed by other cartographers, and his Christian constellations became a historical curiosity.

As regards stellar nomenclature, Schiller chose to use Arabic numbers rather than the Greek letters introduced by Bayer.

Davide Neri

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Schjellerup, Hans Karl Frederik Christian

Born **Odense, Denmark, 8 February 1827**
Died **Copenhagen, Denmark, 13 November 1887**

An astronomer who made a specialty of compiling reference data useful to others, Hans Schjellerup was a watchmaker in early life. In 1851, he became an assistant at the Copenhagen Observatory. There he computed planetary and cometary orbits and compiled a star catalog. In 1866, Schjellerup published a well-known catalog of red stars.

Schjellerup rediscovered, translated, and edited for publication an important work by **Al-Sufi**, which he saw as a bridge in time between the uranometry of **Ptolemy** and the work of **Friedrich Argelander**.

Schjellerup was an associate of the Royal Astronomical Society. A crater on the Moon is named for him.

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Schlesinger, Frank

Born **New York, New York, USA, 11 May 1871**
Died **Lyme, Connecticut, USA, 10 July 1943**

Frank Schlesinger is best known for his contributions to the photographic determination of stellar distances, motions, and positions. He was the youngest of the seven children of Joseph William and Mary (*née* Wagner) Schlesinger, German immigrants to the United States. In 1890, he received a B.S. degree from the College of the City of New York. For 5 years, Schlesinger worked as a surveyor before receiving a fellowship that enabled him to become a full-time graduate student at Columbia University.

Schlesinger received his Ph.D. degree from Columbia University in 1898. From 1899 to 1903, he was in charge of the station of the International Latitude Service in Ukiah, California. In 1903, Schlesinger became a research associate at the Yerkes Observatory, holding that position until he assumed the directorship of the Allegheny Observatory of the University of Pittsburgh in 1905. Following the entry of the United States into World War I, Schlesinger briefly served as an aeronautical engineer for the United States Signal Corps. In 1920, he left Allegheny to become director of the Yale University Observatory, where he remained until his retirement in 1941.

Schlesinger married Eva Hirsch of Ukiah, California, in 1900. Following her death in 1928, he married the former Mrs. Philip W. Wilcox in 1929. He had one son by his first marriage, Frank Wagner Schlesinger, who would himself become a well-known planetarium director.

Schlesinger's doctoral dissertation dealt with the measurement of star positions on photographic plates taken by **Lewis Rutherfurd**, a pioneer in astronomical photography. Schlesinger became interested in the possibility of measuring distances to stars by accurately determining their annual trigonometric parallaxes using photographic methods. The first measurements of stellar trigonometric parallaxes had been made in the 1830s, when careful observations revealed small shifts in the positions of three stars, 61 Cygni (by **Friedrich Bessel**), Vega (by **Wilhelm Struve**), and α Centauri (by **Thomas Henderson**), as the Earth orbited the Sun. Because the size of the shift in position due to parallax is inversely related to distance, these measurements allowed the distances of the three stars to be determined. However, progress throughout the remainder of the 19th century was slow. Visual observations made with instruments such as the heliometer had by the 1890s produced reliable parallaxes for only 30 stars. Early applications of photography to the determination of parallaxes, while promising, had not yet led to large improvements. Schlesinger believed that significant advances were possible using photographic methods, but he did not have an opportunity to attempt such determinations until he arrived at Yerkes Observatory.

The main instrument of the Yerkes Observatory was its 1-m refractor. That telescope's long focal length provided a photographic plate scale adequate for the accurate measurement of stellar positions, a necessary condition for parallax observations. At Yerkes, Schlesinger began to develop techniques for determining stellar parallaxes, including prescriptions for the taking of the photographic plates, for the measurement of star positions on those plates, and for the reductions needed to turn those measurements into actual parallaxes. This work would not come to full fruition until after Schlesinger left Yerkes for the Allegheny Observatory, but the classic papers on the subject that he published in 1910 and 1911 would guide not only his own work, but also that of several observatories that undertook the photographic determination of stellar parallaxes. In 1914, Schlesinger began parallax observations using the newly completed Allegheny Observatory's long-focus photographic Thaw telescope. When he assumed the directorship of the Yale University Observatory, Schlesinger oversaw the construction of a refracting telescope of 66-cm aperture in Johannesburg, South Africa, specifically designed to extend his work on the determination of stellar parallaxes to the hitherto neglected Southern Celestial Hemisphere. The methods that Schlesinger developed allowed stellar parallaxes to be determined with greater accuracy than ever before. Distances accurate to 15% or better could be determined for stars within 10 parsecs (33 light years) of the Sun, and useful results could be obtained for distances approaching 100 parsecs.

When in 1924 Schlesinger published the first *General Catalogue of Stellar Parallaxes,* he was able to list 1,870 trigonometric parallax determinations, the great majority of which were determined photographically. The second edition of the *Catalogue*, published in 1935, listed data for 7,534 stars, including trigonometric parallaxes for about 4,000 stars. Photographic observations made with long-focus refracting telescopes would remain the chief source of trigonometric parallax determinations throughout much of the 20th century.

At Yale, Schlesinger began a second large astrometric program. In the 19th century, the German Astronomische Gesellschaft had organized the measurement of the positions of stars down to the ninth magnitude using the meridian circle techniques of the day. Schlesinger began to reobserve the stars of the Astronomische Gesellschaft catalogs using wide-field photographic cameras. His goal was to remeasure the positions of the stars and, by seeing how much they had moved in the intervening years, determine their proper motions. The work on these "zone catalogues" was mainly carried out while Schlesinger was at Yale, with the assistance of Ida M. Barney. At the time of Schlesinger's death, 14 volumes of the zone catalogs had been published, including data on 92,329 stars. After Schlesinger's death, the zone catalog project would be continued at Yale under the direction of Barney, **Dorrit Hoffleit**, and **Dirk Brouwer**, eventually yielding data for more than 227,000 stars. In the production of the zone catalogs, as in his other research, Schlesinger developed reduction methods that saved time without sacrificing accuracy, an important consideration in the days before automated measuring engines and electronic computers.

In 1930, Schlesinger published the first edition of the *Catalogue of Bright Stars*. This was a compilation of data on the stars brighter than visual magnitude 6.5 that had been included in the *Harvard Revised Photometry* catalog. A second edition of this useful compilation, coauthored with **Louise Jenkins**, appeared in 1940. The *Catalogue of Bright Stars*, too, would have continued life after Schlesinger's death, with the compilation of later editions by Hoffleit and her collaborators.

Schlesinger was first elected to the council of the American Astronomical Society in 1908 and, after serving as a vice president of the society, became its president from 1919 to 1922. He was a vice president of the International Astronomical Union from 1925 to 1932, and served as president from 1932 to 1935. Schlesinger received many honors, including honorary degrees from the University of Pittsburgh and Cambridge University, the Gold Medal of the Royal Astronomical Society, the Valz Medal of the French Academy of Sciences, the Bruce Medal of the Astronomical Society of the Pacific, and the Townshend

Medal of the College of the City of New York. He was elected a member of the National Academy of Sciences in 1916 and was an honorary member of several foreign societies. Schlesinger was the organizer of the Neighbors, an informal but influential group of (male) astronomers in the northeastern United States.

Horace A. Smith

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Schmidt, Bernhard Voldemar

Born **Island of Naissaar near Tallinn, (Estonia), 30 March 1879**
Died **Hamburg, Germany, 1 December 1935**

German optician Bernhard Schmidt gave his name to a telescope type that permitted obtaining sharp images over a very wide field quickly. It involves a spherical primary mirror and a transparent corrector plate that largely removes the focus errors called coma and spherical aberration.

Schmidt was the first of five children of Karl Konstantin Schmidt and his wife, Maria Helene. His father was a writer, farmer, and fisherman on the island of Naissaar, in the Baltic Sea. Swedish was the language spoken on the island and in school, but at home the family spoke German. At the age of 15, Bernhard experimented with gunpowder and lost his right hand and forearm in an accident. This did not prove too much of a handicap, for later that year he built his own camera, photographed local people, and sold the pictures.

In 1895, Schmidt left Naissaar for Tallinn where he found work as a telegraph operator with a rescue team. Between 1895 and 1901, he also worked as a photographer and in the "Volta" electromotor factory. Around 1900, he made his first 5-in. diameter object glass; it was not perfect, but he improved it as he made observations of Nova Persei 1901. Schmidt moved to Göteborg, Sweden, to attend a technical school, the Chalmers Institute, but after a few months moved on to Mittweida in southeastern Germany. There, he improved his knowledge of optics with Dr. Strehl as his teacher at the Technikum Mittweida. That technical college was practically oriented; Schmidt favored hands-on practice to theoretical work. In the summer of 1903, he fashioned a mirror for the Altenburg Observatory, probably his first work geared toward professional use. Most of the mirrors Schmidt had made previously were sold to amateurs, and provided income to live on, since he got little financial support from his parents.

In 1904, Schmidt opened his own optical workshop in a small house in Mittweida, and later moved to more spacious quarters. He offered his skills to observatories to improve their optics, lenses, and mirrors, and in 1905 received a commission for a reflecting telescope from the Potsdam Astrophysical Observatory. Eventually, Schmidt was well known to astronomers all over Germany. In 1913, he was asked to rework a 50-cm telescope lens originally made by Steinheil & Sons. After Schmidt's reworking of this lens, **Ejnar Hertzsprung** was able to make some very delicate observations of double stars with this telescope at Potsdam, and it remained in use until 1967. Schmidt also sold two mirrors to the University of Prague, one of 60-cm diameter and another of 30 cm. Around 1926, he was offered work at the Zeiss optical shop in Jena, Germany, but although his own business was slowing down Schmidt had been independent all his life, and wanted to work only at his own pace, so he refused the offer.

In 1927, Schmidt sold his shop and moved to Hamburg to work at the nearby observatory in Bergedorf as a freelance optician. The director then was Richard Schorr, who knew about Schmidt's abilities. He also knew that Schmidt liked French brandy and paid him only small sums of money at a time. "The optician," as Schmidt was called, also made observations with various instruments; in 1928 he took pictures of Jupiter, Saturn, and the Moon with his own telescope.

During a journey back to Hamburg after observing the solar eclipse of 1929 in the Pacific Ocean, Schmidt discussed the possibility of a special camera for wide-angle sky photography with **Walter Baade**, an astronomer on the Bergedorf staff. With Baade's encouragement, after returning to his workshop at the observatory, Schmidt developed his now famous wide-field telescope. He completed his first version of this design in 1930; it included a spherical main mirror with a diameter of 44 cm and a corrector plate, placed at the radius of curvature of the main mirror, with a diameter of 36 cm. The corrector plate, shaped in a complex figure of a circular torus, compensated for the spherical aberration introduced by the primary mirror. The overall focal ratio was *f*/1.75, the field of view 7.5°. The very first photograph taken at night with this new instrument clearly and legibly showed a tombstone in a distant graveyard.

Schmidt himself made only this one instrument. However, when Baade joined the Mount Wilson Observatory staff in 1931 and told his new colleagues about the great success of the Schmidt design, there was an immediate and enthusiastic rush to implement this new technology in the Mount Wilson optical shops and elsewhere. Their success in this pursuit owed much to Schorr's direct intervention to ensure publication of Schmidt's only technical publication on this design. Schmidt's concept for a wide-field telescopic camera for stars and other celestial objects has been widely applied in other fields. In X-ray technology, for example, the urgent need to improve photographic recording of images prompted the employment of **Jesse Greenstein** and **Louis Henyey** to supervise the design and construction of a prototype 70-mm X-ray camera in the optical shops of Yerkes Observatory.

Schmidt's original camera is now in the museum of the Hamburg Observatory in Germany. The 48-inch Schmidt telescopes at Palomar, and in Australia and Chile, were used for the most extensive sky survey ever made. Data from these provided the initial guide star catalog for the Hubble Space Telescope, and digitized versions of the surveys still are in frequent use.

Schmidt died of pneumonia in a mental hospital, shortly after returning from a trip to the Netherlands. He was buried in a cemetery very close to the observatory. Minor planet (1743) Schmidt was named in honor of Bernhard Schmidt.

Christof A. Plicht

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Schmidt, Johann Friedrich Julius

Born **Eutin, (Schleswig-Holstein, Germany), 26 October 1825**
Died **Athens, Greece, 7 February 1884**

German observer Julius Schmidt compiled the most complete maps of the Moon of his generation and reported changes in the appearance of one crater that were widely accepted at the time. In an era when study of the Moon had become increasingly specialized and knowledge of its topography so comprehensive that it led to the formation of a committee of British observers to further its mapping, Schmidt worked unaided and alone. It was plausibly suggested by Harvard College Observatory astronomer **William Pickering** that Schmidt "perhaps devoted more of his life than any other man to the study of the Moon."

Schmidt was the son of Carl Friedrich Schmidt, a glazier by profession, and Maria Elisabeth Quirling. At the age of 14, young Schmidt chanced upon a copy of **Johann Schröter**'s *Selenotopographische Fragmente*. He was so fascinated by its pictures of mountains and craters that the future direction of his life was determined then and there. Schmidt immediately began to study the Moon himself, using a small telescope made with lenses ground by his father.

Schmidt's first view of the Moon through a good telescope came in July 1841, when A. C. Petersen, director of the Altona Observatory near Hamburg, showed him the imposing craters Bullialdus and Gassendi. He also saw for the first time a copy of the great 1837 map of the Moon prepared by **Wilhelm Beer** and **Johann von Mädler**. Soon afterward, Schmidt moved to Hamburg and for several years made frequent observations with the telescopes of the Altona Observatory.

A strange interlude followed in 1845, when Schmidt accepted a position in the private observatory of **Johann Benzenberg** at Bilk, near Düsseldorf. Benzenberg was preoccupied with the search for a possible intra-Mercurial planet and did not allow Schmidt to use his large refractor, apparently for no better reason than that "its outward good looks and polish might not suffer by handling." Instead, he gave Schmidt access only to a "wretched instrument." After a few months, Schmidt left Bilk in disgust and took a position under **Friedrich Argelander** at the Bonn Observatory. Although most of his time was taken up with entering meridian circle observations of stars for Argelander's great catalog, the *Bonner Durchmusterung* (Bonn Survey), he made as many lunar observations as he could.

In 1853, Schmidt left Bonn for E. von Unkrechtsberg's observatory at Olmütz (now Olomouc), in Moravia, where he made some 3,000 measurements of the heights of lunar mountains with a filar micrometer. This work was published in an 1856 treatise, entitled *Der Mond* (The Moon), in which Schmidt attempted to provide a quantitative comparison of lunar and terrestrial features. He prudently warned against taking the apparent similarities between the Moon and Earth too seriously.

On 2 December 1858, Schmidt assumed the directorship of the Athens Observatory in Greece, where he would remain for the rest of his life. When he set foot on Greek soil at Piraeus, Schmidt was still a comparatively young man, full of energy. Arriving at the observatory, he found it in a state of disrepair and neglect. Within only a year, however, Schmidt was able to restore to working order a fine 6.2-in. refractor by the Viennese optician Georg S. Plössl, which served as the main instrument for his lunar work over the next quarter of a century.

By 1865, Schmidt had assembled so many lunar observations that he began laying down his surveys of selected regions on a 6-ft. diameter map. The next year, he began to construct a 1-m map based on **Wilhelm Lohrmann**'s observations, which had been entrusted to Schmidt by Lohrmann's publisher.

At first, Schmidt planned to enter details from his own observations onto Lohrmann's map, but he soon abandoned this approach in favor of something far more ambitious – nothing less than a fresh topographic map of the Moon roughly 2-m diameter, which, like Lohrmann's original design, was to be divided into 25 sections. Schmidt hoped to record all of the details of the lunar surface visible through his 6.2-in. refractor, but gradually came to the realization that such a feat would require "more powers of endurance and a longer lifetime than are allotted to mortals."

It was while Schmidt was involved in this lengthy series of observations that he came across something startling but not entirely unexpected. In 1866, he announced that the tiny crater Linné in Mare Serenitatis had undergone a profound change. He maintained that, prior to 1866, Linné had always been recorded as a crater about 6 miles in diameter and "very deep," but had been suddenly reduced to a diffuse white patch. As a recent eyewitness of volcanic eruptions on the Aegean island of Santorini, Schmidt proposed that Linné had been filled in by a similar "eruption of fluid or powdery material."

Given the daunting complexity of lunar detail, the variable effects of shadow, foreshortening, and libration as well as the inevitable deficiencies of the selenographic record, the surprising fact is that Schmidt's claim of a definite change was widely and uncritically accepted. Despite the fact that the evidence of change was always weak, the alleged alteration of Linné would not be thoroughly discredited for more than a century.

In July 1874, Schmidt presented his lunar map to the Berlin Observatory, where it excited admiration as a performance highly creditable to "Teutonic intellect and perseverance." Before long, it was being touted as a uniquely Prussian achievement. Its 25 sections were photographed at the General Staff Office under the direction of Count von Moltke; its publication as the *Charte der Gebirge des Mondes* (Map of the Mountains on the Moon) was sponsored by the Crown Prince of Prussia himself.

After the first copies of the map appeared in 1878, the English astronomer **John Birmingham** commented:

> In even a cursory examination of Schmidt's map its completion by a single observer must seem almost incomprehensible …; but it requires protracted study to well realize the extent of the work. Any person who tries with the aid of a 6-inch telescope to give a closely detailed delineation of even a small area of the Moon, will soon conclude that the period of thirty-three years was comparatively a very short one for the accomplishment of Dr. Schmidt's great task.

In his popular book entitled *The Story of the Heavens* (1886), Sir **Robert Ball** marveled:

> To give some idea of Schmidt's amazing industry in lunar researches, it may be mentioned that in six years he made nearly 57,000 individual settings of his micrometer in the measurement of lunar altitudes. His great chart of the mountains in the Moon is based on no less than 2,731 drawings.

According to Schmidt's own rather compulsive analysis, Lohrmann had charted 7,177 craters and Mädler 7,735; his own map recorded no less than 32,856. The superiority of Schmidt's map was also apparent in his record of rilles – the 71 on Mädler's map paled in comparison with his own 348.

Schmidt also had a keen interest in seismology. At the age of 20, he began to collect materials for a global earthquake catalog, and he contributed to Johann J. Noeggerath's study of the 1846 Rhineland earthquake by calculating the propagation speed of the seismic wave. In 1874, he published a study of four volcanoes: Santorini, Etna, Vesuvius, and Stromboli. Schmidt's *Studien über Erdbeben* (Studies on earthquakes), a comprehensive catalog of earthquakes recorded in southeastern Europe since ancient times, was issued the following year.

Schmidt reorganized the meteorological service of the Athens Observatory. He made meteorological observations from locations throughout Greece and regularly submitted data to the Paris Observatory. These results were presented in his 1864 work, *Beiträge zur Physikalischen von Griechenland*. Schmidt also dabbled in archeology and made a concerted effort to find the site of ancient Troy.

Schmidt was awarded an honorary doctorate from the University of Bonn in 1868. Fittingly, a crater on the Moon is named for him.

Thomas A. Dobbins and *William Sheehan*

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Schmidt, Otto Iulevich

Born **Mogilyov, (Ukraine), 30 September 1891**
Died **7 September 1956**

Russian geophysicist Otto Schmidt led the 1937 Soviet air expedition to the North Pole. Thus, he may have been the first person actually to reach latitude 90° N. His subsequent fame brought him a directorship within the Academy of Sciences. However, Joseph Stalin relieved Schmidt of this position during World War II. (Whether it was simply because of his German surname is unknown.)

Freed of administrative responsibilities, Schmidt turned – for the first time – to a research field in which he had long-standing interest: solar-system cosmogony. Schmidt hypothesized that the planets were formed from "meteoritic" material that had been gravitationally captured by the Sun as it passed through an interstellar cloud.

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Schöner, Johannes

Born **Karlstadt near Nuremberg, (Germany), 16 January 1477**
Died **Nuremberg, (Germany), 16 January 1547**

The *Narratio Prima* of Johannes Schöner was the first publicized account of the Copernican theory.

Little is known about Schöner's youth. He matriculated at the university in Erfurt in 1494, but apparently did not complete a degree there. After being ordained as a priest in 1500, Schöner settled in Nuremberg in 1504, where he immediately devoted time to making celestial observations. In Nuremberg, he was also able to study briefly under **Bernard Walther**, until the latter's death in 1504. On 8 January and on 18 March 1504, Schöner made observations of the planet Venus, which he sent to **Nicolaus Copernicus**. Copernicus later used these and other observations in his theory of Mercury. Schöner took priestly orders in 1515 and was appointed to a position in Bamberg. In the same year, his first terrestrial globe was printed. Due to neglect of his clerical duties in Bamberg, Schöner was relocated to the small village of Kirchehrenbach, shortly after 1520. Catholic leaders were concerned not only about Schöner's negligence; Cardinal Campeggio called Schöner's orthodoxy into question, claiming that Schöner was a "Lutheran" because he was married. By 1526, it was clear that Schöner had Lutheran affiliations, for he had accepted the chair of mathematics at the new Lutheran Gymnasium in Nuremberg upon the request of Martin Luther's right-hand man Philip Melanchthon and upon the urging of the reformer Joachim Camerarius. It is still unclear when Schöner first married or had children, but in 1527 he married Anna Zelerin, with whom he had at least three sons. One of the sons, Andreas Schöner (born: 1528), followed in his father's footsteps as a mathematician and editor. As the professor of mathematics in Nuremberg, Johannes Schöner issued regular yearly prognostications in German between 1529 and 1547 for the city of Nuremberg. During these years, he also edited and had printed many of the works of **Johann Müller** (Regiomontanus) and **Johannes Werner**.

Among Schöner's contacts was **Rheticus**, who convinced Copernicus to let him write and have printed the *Narratio Prima*, which Rheticus then dedicated to Johannes Schöner. Later, Schöner was among those who encouraged Copernicus to publish *De revolutionibus* (On the revolutions) that was published in Nuremberg in 1543. Schöner defended the legitimacy of making astrological predictions, and he held that the Copernican system was not unfavorable toward astrology.

Schöner showed an interest in acquiring the works of Regiomontanus, many of which he later edited for publication. While still working as a cleric in Bamberg in 1509, Schöner bought the almanacs of Regiomontanus for the years 1464–1484. Schöner later obtained many of Regiomontanus's unpublished manuscripts that he then edited and printed. In 1531, Schöner began with Regiomontanus's treatise on the problems of determining the magnitude and location of comets, entitled *De cometae magnitudine longitudine ac de loco eius vero problemata XVI*. Among the other works of Regiomontanus that Schöner edited for publication were *De triangulis omnibus* (1533), which was printed at the press of Johannes Petreus, and *Opusculum geographicum* (also in 1533), which contained Regiomontanus's arguments against the rotation of the Earth on an axis.

In addition to the recovery of Regiomontanus's work, Schöner printed his own work and the works of others. One of Schöner's best-received publications was his own *Tabulae resolutae*, which saw its first publication in 1536. Melanchthon praised Schöner's tables for showing "the position of all the stars and not for one year only but many centuries." Andreas Schöner edited and printed his father's collected works in 1551, which contained the *Tabulae resolutae*. The tables were printed again separately in 1587/1588. In addition to casting horoscopes and issuing annual prognostications, Schöner compiled the *Opusculum astrologicum*, which contained among other things Eberhard Schleussinger's *Assertio contra calumniatores astrologiae* (Assertion against the calumniators of astrology).

In 1544, toward the end of his life, Schöner published the observations of both Regiomontanus and Walther, including their observations of eclipses, comets, and positions of the planets and fixed stars. These observations proved to be valuable to later astronomers such as **Tycho Brahe** and **Johannes Kepler**. In 1546, Schöner's final publication was Werner's work on weather predictions.

Derek Jensen

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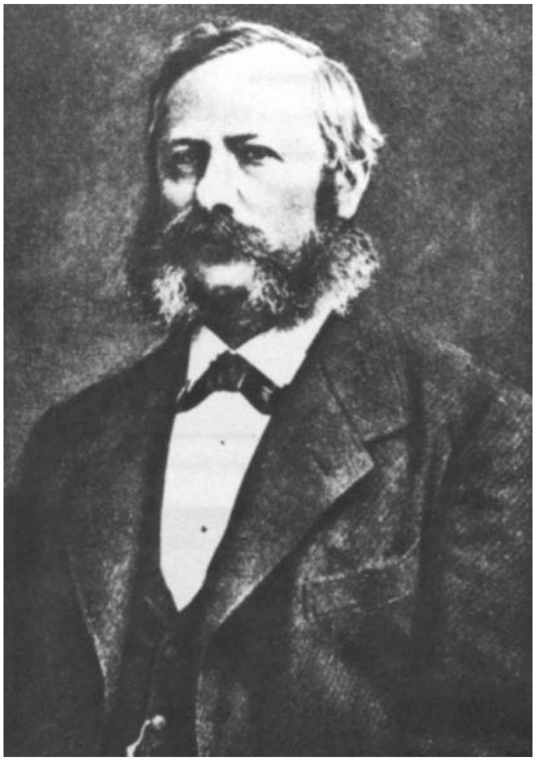
Schönfeld, Eduard

Born **Hildburghausen, (Thüringia, Germany), 22 December 1828**

Died **Bonn, Germany, 1 May 1891**



Eduard Schönfeld directed two astronomical observatories, single-handedly compiled the first southern extension of the *Bonner Durchmusterung* [BD] star catalog, and was a cofounder of the Astronomische Gesellschaft [AG]. Schönfeld was the son of merchant Joseph Schönfeld and his wife Louise (*née* Fauß) Schönfeld. His mother taught young Eduard the basics of reading and mathematics before he started school. He attended a gymnasium in Hildburghausen and studied architecture at the Hanover Technische Hochschule until he was expelled in 1849 for his participation in political events of the previous year.

Schönfeld continued his studies at Kassel and later at the University of Marburg, where he attended lessons of Christian Ludwig Gerling, who had built a small observatory. Together with Gerling's assistant, **Ernst Klinkerfues**, he planned to observe an occultation of the star γ Arietis. When Klinkerfues did not get to the observatory in time, Schönfeld made the observations himself, calculated the results, and presented them to his professor on the following morning. As a reward for this work, he received a key to the observatory and encouraging words to continue his work. His first observation, published in the *Astronomische Nachrichten*, was followed by many others.

In 1851, Schönfeld visited **Friedrich Argelander** in Bonn. Discussing Schönfeld's wish to become an astronomer, Argelander tried to discourage the student, but finally accepted him in 1852. The following year, Schönfeld became Argelander's paid assistant, when **Johann Schmidt** left Bonn for a new observatory at Olmütz (now Olomouc) in Moravia. In 1854, Schönfeld received his Ph.D. with a thesis entitled, "Nova Elementa Thetidis." Along with two other assistants, Wilhelm Julius Foerster and **Karl Krüger**, Schönfeld kept up work on the *Bonner Durchmusterung*. During this time, however, he also developed secondary interests in minor planets and variable stars. Whenever conditions allowed, he observed the stars β Persei (Algol) and S Cancri to record complete cycles in their brightness variations.

In 1859, Schönfeld left Bonn for Mannheim, invited by the Grand Duke of Baden to direct the new observatory there. In the previous year, he had declined an invitation from **Friedrich Struve** to come to the Pulkovo Observatory, indicating that work on the *Durchmusterung* was far from complete. The Mannheim Observatory, which included living quarters for the director, consisted of a single building: a 33-m (100-ft.) tower with 196 steps leading to its upper platform. For his work at Mannheim, Schönfeld ordered a 16.5-cm (6.6-in.) diameter telescope whose manufacture he supervised at the workshop of Karl Steinheil, in Munich.

In 1860, Schönfeld married Helene Noeggerath, the daughter of geology professor Johann J. Noeggerath. The couple later had three children.

Schönfeld's principal scientific work continued to be the *Durchmusterung*, but he observed minor planets, comets, variable stars, and nebulae. Of the latter he published two catalogs, in 1862 and 1875, totaling 489 objects. Two more catalogs were published in 1866 and 1874, presenting data on 119 and 143 variable stars.

In 1862, Schönfeld received another invitation from Pulkovo, this time from the younger **Otto Wilhelm Struve**, who had succeeded his father as observatory director. The Mannheim astronomer was torn between his desire to operate better equipment and his well-established career in Germany, but he again declined the invitation.

A change in his life came when he was ordered to take charge of the duties of the Eichamt (Office of Weights and Measures). This opportunity allowed Schönfeld to travel at government expense. His professional demeanor led toward his election to the Normal-Eichungskommission (National Commission of Standards). During these business trips, he had the opportunity to meet with numerous colleagues and to discuss astronomical matters. Thus, Schönfeld and Foerster invited the astronomical community to establish the AG. The society's first meeting took place at Heidelberg in 1863. Schönfeld served as its secretary from 1875 until his death.

The volumes of the *Bonner Durchmusterung* that comprised the northern skies had been published between 1857 and 1863. Upon Argelander's death in 1875, Schönfeld was appointed to his now-vacant post at Bonn. Even Argelander's son-in-law, Krüger (who then worked in Helsinki), supported Schönfeld in a letter to Foerster. In one of the towers, Schönfeld found a 15.9-cm (6.25-in.) telescope made by Hugo Schröder in Hamburg, acquired the year before by Argelander. With this more exact and larger instrument, Schönfeld continued work on the *Durchmusterung*, extending its coverage from −2° to −23° declination.

Schönfeld's observations were completed by 1881, but he continued to rework the positional data for several more years. In 1886, the *Bonner Durchmusterung des südlichen Himmels* [BDS], was printed. It reproduced 133,659 stars on 24 charts. Ironically, in his introduction to the BDS, Schönfeld indicated that future star atlases would likely be prepared by the newer methods of astrophotography; a prediction that was demonstrated in years ahead.

In 1887, Schönfeld declined an invitation to direct the Strasbourg Observatory constructed by **Friedrich Winnecke**. The University of Bonn elected Schönfeld its headmaster as a reward for his choice to stay. Other honors followed – he was elected a member of the Prussian Academy of Sciences, became a recipient of the Watson Medal of the United States National Academy of Sciences, and received another medal from Russia. In 1890, Schönfeld fell ill and went to Baden-Baden to find a cure, but continued to observe the brighter variable stars.

Minor planet (5926) Schönfeld and a lunar crater are named in his honor.

Christof A. Plicht

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Schreck, Johann

Born ***circa* 1576**
Died **Beijing, China, 13 March 1630**

Swiss Jesuit Johann Schreck was a friend of **Galileo Galilei**. He was among the first foreign missionaries hired by the emperor to improve the Chinese calendar. After Schreck's death, this task passed to fellow Jesuits **Johann Schall von Bell** and **Giacomo Rho**.

Alternate names

Terrentius
Terrenz, Jean

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Schrödinger, Erwin

Born **Vienna, (Austria), 12 August 1887**
Died **Vienna, Austria, 4 January 1961**

Austrian physicist Erwin Schrödinger is chiefly known for the development of wave mechanics, as expressed in a fundamental equation that bears his name. He was educated in Vienna by a private tutor before attending that city's academic gymnasium. At the University of Vienna, he became a protégé of Ludwig Boltzmann's successor, Fritz Hasenöhrl. Schrödinger completed his Ph.D. in theoretical physics in 1910 before accepting a research appointment in experimental physics under Franz Exner and Friedrich Wilhelm Georg Kohlrausch. After he completed his *Habilitation* (the post-doctoral requirement in Germany for teaching at a university) in 1914, World War I broke out. Schrödinger became an artillery officer but nevertheless managed to publish several important papers while serving, with distinction, on the Italian front. A tour of duty in Hungary included a battle victory and another physics paper. Upon his return to the Italian front, Schrödinger received a medal for outstanding service as commander of his battalion.

After the war, Schrödinger became a research assistant to Max Wien. In 1920, he was appointed a professor at Stuttgart University and that same year married Annemarie Bertel. There, his close association with philosopher Hans Reichenbach had a lasting influence on his subsequent work, the most important of which he did in Switzerland, at the University of Zürich. At Zürich, Schrödinger became a close colleague of **Hermann Weyl** (one of David Hilbert's students) and Peter Debye (winner of the 1936 Nobel Prize in Chemistry). All of these remarkable influences culminated in Schrödinger's crowning achievement, his development in 1926 of wave mechanics – what is now known as Schrödinger's equation – severely modifying the classical laws of mechanics on small scales. One year later, he was awarded the Max Planck Chair in Physics at the University of Berlin. In 1933, Schrödinger won the Nobel Prize for Physics (along with **Paul Dirac**).

Schrödinger's groundbreaking discovery, namely, that the corpuscular conception of matter could be explained purely in terms of waves, grew out of his deep skepticism of **Niels Bohr**'s hypothesis regarding the discontinuous nature of electron orbitals, along with his deep mathematical intuition that atomic spectra could be represented by eigenvalues. Extending Louis Victor de Broglie's revolutionary conception of matter waves, in which the behavior of atomic particles is governed by the laws of wave propagation, Schrödinger provided a theoretically satisfying and logically consistent picture of the quantum universe in which the problematical, discrete nature of matter is replaced entirely by waves. Individual atoms, in Schrödinger's wave theory, are conceived as having no determinate size, and are but vibrations in space-time extending to infinity, themselves limited to a sequence of discrete patterns governed by Schrödinger's equation. Thus, instead of dealing with fixed positions and velocities of "real" particles, Schrödinger's wave function, ψ, expresses the magnitude of the matter waves that vary across space from point to point and through time from moment to moment.

In this scenario, the probability of finding an "individual" particle at a "particular" position is determined by the absolute square of the wave function $\psi(\chi)$, giving the probability distribution for all the coordinates of the system in the state represented by the wave function. Moreover, as Schrödinger himself went on to show, his wave mechanics and Werner Heisenberg's matrix mechanics were equivalent and both accounted naturally, and in a logically consistent way, for the empirically verified quantization of energy. Thus, what is generally known as quantum mechanics is in large part a synthesis of Schrödinger's and Heisenberg's conceptually distinct yet empirically complementary theories.

In 1934, Schrödinger was offered a position at Princeton University but instead accepted a position in his native Austria at the University of Graz. Four years later, after the German *Anschluss*, the university was renamed Adolf Hitler University and Schrödinger was abruptly dismissed from his position. He fled to Rome, then Oxford, England, and taught for one year at the University of Ghent. Schrödinger then accepted an offer to join the Institute for Advanced Studies in Dublin; he remained there until his retirement in 1956, whereupon he returned to his Vienna.

Daniel Kolak

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Schröter, Johann Hieronymus

Born **Erfurt, (Thüringia, Germany), 30 August 1745**
Died **Lilienthal, (Niedersachsen, Germany), 29 August 1816**

Observational astronomer, telescope builder, and noted selenographer, Johann Schröter provided the first extensive description of lunar rilles and solar granulation (convection cells). He was also the first to establish the presence of an atmosphere around Venus.

Schröter's father, Paul Christoph Schröter, was a lawyer who married Regina Sophia Streckroth in 1729. In 1764, Johann went to Göttingen to study law. But the observatory director, Abraham Gotthelf Kästner, awakened a love of astronomy in the young jurist. In 1777, Schröter was appointed secretary of the Royal Chamber (of King George III) in Hanover.

Being musically inclined, Schröter got to know the family of regimental bandmaster Isaak Herschel, who had nine children. The eldest of these, **William Herschel**, was a self-taught astronomer. Returning from a visit to England, William's brother Dietrich brought Schröter his first telescope, a small achromatic Dolland refractor.

There were many parallels between the lives of William Herschel and Johann Schröter. Both were German-born, and knew from their childhoods the meaning of penury. Both had a passionate fondness for music, and each enjoyed the tender care of a devoted sister. Each had command of the greatest telescopes of his own country. Both were experts at mechanical contrivances; each was supremely energetic, patient, industrious, and conscientious.

The decisive event of Schröter's life took place in 1781, with Herschel's discovery of Uranus. In a spirit of emulation, Schröter resolved to dedicate himself toward astronomy. He resigned his court position in Hanover to assume the less-demanding post of chief magistrate of Lilienthal, a village on the moor near Bremen. He took up residence in the Amthaus (city hall) in 1782.

As a government official, Schröter made use of his first income to place an order with Herschel for a 4-ft. telescope and to erect a two-story observatory. His enthusiasm was infectious; two of his servants, coachman Arnd Harjes and gardener Harm Gefken, became keen coworkers and obviated the need for a trained mechanic. From 1800 onward, Harjes also did most of the illustrations for Schröter's books.

Larger and larger instruments were installed, eventually numbering more than a dozen. Schröter obtained two mirrors, 4.75 in. and 6.5 in. in diameter, made by Herschel himself. The larger of the two mirrors he assembled into a 7-ft. reflector that was in every respect identical with the one Herschel had used to discover Uranus. When Schröter began to use it in 1786, it was the largest telescope in Germany. Ultimately, Schröter's mirrors were also ground in Lilienthal. Gefken taught himself this art, where, adjoining the observatory, the first workshop in Germany for making reflecting telescopes was erected.

The impetus to construct telescopes in Lilienthal was given by Johann Gottlieb Friedrich Schrader, a professor of physics in Kiel, who stayed in Lilienthal in 1792/1793. With Schröter, he constructed a telescope of 25-ft. focal length. Immediately after his return to Kiel, Schrader erected a 26-ft. telescope. Schröter responded to this news by fashioning another mirror (18.5-in. diameter) with a 27-ft. focal length. It remained the largest in Germany for years to come.

Schröter was no mathematician; his strength lay in making visual observations. He chiefly studied objects in the Solar System, publishing 86 memoranda over 30 years. However, very few of his conclusions have stood the test of time. Perhaps Schröter's best-known work was his book on lunar topography, published as two volumes in 1791 and 1797 (reissued 1802). He made hundreds of drawings of lunar surface features, and described and named the "rilles."

Schröter carried out the first extensive investigation into the physical nature of the planet Mercury. From the blunted appearance of its southern cusp, which seemed unchanged from night to night, he concluded that the planet's rotation period must be nearly 24 hours (the real figure being 59 days).

Schröter was also an active solar observer from 1785 to 1795. He was the first, in 1787, to notice and comment upon the surface feature now known as "granulation." He also gave detailed descriptions of light bridges seen over the umbrae of sunspots.

Schröter carried out many observations of Venus and estimated its rotation period at 23 hours 21 minutes (the real figure being 243 days, retrograde). He found that Venus appears to be at half phase not when theoretically expected (*i. e.*, at quadrature) but a few days before or afterward. This has become known as the Schröter effect. In 1790, Schröter definitely established the presence of an atmosphere around Venus by the observed extension of its cusp (viewed in the crescent phase) beyond a semicircle.

In 1785/1786, Schröter recorded multiple transient dark spots on Jupiter, which have been interpreted as activity in the southern equatorial belt of Jupiter. His observations of Saturn led him to believe that its rings were a solid body, another erroneous conclusion.

The Bremen astronomer **Wilhelm Olbers** often stayed at Lilienthal, and loved to observe with Schröter's instruments. The inaugural meeting of the "Celestial Police" (Vereinigte Astronomische Gesellschaft), on 20 September 1800, was held at Schröter's observatory, and he was elected its president. The role of the "Police" was to search for a supposed "missing planet," located between Mars and Jupiter. After discovery of the first minor planet (1) Ceres, Olbers and Schröter regularly observed it from Lilienthal. In 1805, Schröter published the official report of the "Celestial Police," which included studies of the minor planets (1) Ceres, (2) Pallas, and (3) Juno. Discovery of the third asteroid was made by Schröter's assistant, **Karl Harding**.

In 1815, Schröter transferred his instruments to the University of Göttingen, with the stipulation that he could use them as long as he lived. When the kingdom of Westphalia annexed Lilienthal, Schröter wished to void the sale and ship the instruments to France. The French wanted them, but realized that a second sale would be illegal. Göttingen astronomer **Carl Gauss** tried to enlist the aid of French astronomer **Pierre de Laplace** in the matter, but it was too late.

Schröter was alone with only his servants when Lilienthal was engulfed in war. In April 1813, French troops "broke into the observatory … and with a fury the most unprovoked and irrational[,] destroyed or carried off the most valuable clocks, telescopes, and other astronomical and mathematical instruments," Schröter wrote. Just days before, the only copies of nearly his entire works, deposited in a government office building, were completely burned.

Soon afterward, the French troops were expelled from Germany and Schröter, reinstated as chief magistrate, attempted to rebuild Lilienthal. He fought off despair by writing up his observations of the Great Comet C/1811 F1, and then turned to his observations of Mars. Miraculously, most of those records had escaped the fire. His engraver, Tischbein of Bremen, began to make copper plates of the drawings, but Schröter's eyesight was failing. The project was unfinished at the time of his death. Schröter's work on Mars was posthumously published in 1881.

A crater on Mars is named in Schröter's honor, minor planet (4983) was named Schröteria, and a prominent lunar feature is denoted Schröter's valley. He had been elected a fellow of the Royal Societies of Göttingen, London, and Stockholm, and a member of the Russian Academy of Sciences.

Clifford J. Cunningham

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Schüler, Wolfgang

Flourished **16th century**

While it is universally known as Tycho's supernova, the "new star" of 1572 (B Cas) was first observed 6 November by Wolfgang Schüler in Germany.

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Schumacher, Heinrich Christian

Born **Bramstedt, (Schleswig-Holstein, Germany), 3 September 1780**
Died **Altona, (Hamburg, Germany), 28 December 1850**

Heinrich Schumacher was a reformer of Danish science and the founding editor of the *Astronomische Nachrichten*, the most import astronomical journal of the 19th century. Schumacher, the son of the Danish senior civil servant and chamberlain Andreas Schumacher, was initially taught by the Reverend Johann Friedrich August Doerfer, who was noted for his topographical work in Schleswig and Holstein, as well as at the Altona Gymnasium, where the headmaster was Jakob Struve, the ancestor of the subsequently renowned family of astronomers. Schumacher studied jurisprudence at Kiel, was a private tutor in Livonia, and lectured in law at Dorpat (and simultaneously was active at the observatory there). In 1808/1809, Schumacher went to Göttingen on a royal Danish scholarship to pursue his studies in astronomy under **Carl Gauss**. In 1810, he was extraordinary professor of astronomy at Copenhagen, but, because of differences with the full professor, Thomas Bugge, he remained in Altona and observed from Johann Georg Repsold's observatory in Hamburg. In 1813, Schumacher held a post for a short time at Mannheim, but was not able to carry out observations because of the poor state of the instruments there.

Following the death of Bugge, Schumacher returned to Denmark in 1815. Because the observational instruments at the Copenhagen Observatory on the Round Tower were also inadequate, he devised a project for a Danish land survey, which he carried out in close collaboration with Gauss. Given leave of absence as professor by the king, Schumacher took up residence in Danish Altona. The Danish survey that was implemented from there from 1816 onward was linked to the Hanoverian triangulation, and covered from Skagen in the north to Lauenburg in the south. It was later employed by **Friedrich Bessel** to derive the rotational flattening of the Earth. Together with Bessel and the Danish physicist H. C. Oersted, Schumacher worked to reorganize the Danish system of weights and measures (including measuring the length of a seconds pendulum at Gueldenstein Castle in Holstein), and linked the Danish units to the Prussian system. He established a small, efficient observatory in Altona.

The most important of Schumacher's spheres of activity was the publication of Danish calendars, astronomical tables, and ephemerides, specifically for seamen (from 1820 onward), as well as (from 1821) founding and publishing the astronomical journal *Astronomische Nachrichten*. He did not feel any call to carry out decade-long, nightly observational activities, which may itself have been the result of his uncertain health.

Schumacher's expertise, his careful approach, his diplomatic skills, and his acquaintance with the leading astronomers of the time, soon turned the *Astronomische Nachrichten* into the international center for astronomical communication. Of particular importance was the regular publication schedule, thanks to the direct support for the undertaking given by the Danish kings Frederik VI and the later Christian VIII, as well as by the scholarly Finance Minister Johann Sigismund von Moesting.

By the time of his death, Schumacher had edited 30 volumes of the journal. During this time, there were hardly any astronomers of significance who did not publish their work in it. Throughout this period, the world was informed of the latest discoveries either through the *Astronomische Nachrichten* or through the separately issued *Zirculare* (Circulars). The significance of the *Astronomische Nachrichten*, and Schumacher's work in making it the medium of communication for the international community of astronomers cannot be over-estimated; it was fundamental. For three decades, Schumacher undertook an incredible amount of work, which involved dealing with manuscripts and in carrying on, single-handedly, an extensive correspondence. The letters to Schumacher that have been preserved must, on their own, exceed 15,000.

Schumacher's *Astronomische Nachrichten* reached Volume 327 in 2006 and is the oldest astronomical journal in continuous publication. Its editorial offices are now at the Potsdam Astrophysical Institute.

Jürgen Hamel
Translated by: *Storm Dunlop*

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Schuster, Arthur

Born **Frankurt am main, (Germany), 12 September 1852**
Died **Berkshire, England, 14 October 1934**

German–English theoretical astronomer Arthur Schuster is commemorated in the Schuster–Schwarzschild (or reversing layer) approximation for analyzing the spectra of stars to learn their chemical composition. The idea is that you can treat the situation as if there were a hot layer, the photosphere, emitting a blackbody continuum, and a cooler layer above which imposes the absorption lines. The opposite approximation, that the continuum source and absorbing atoms are uniformly mixed, is called the Milne–Eddington approximation, and real stars come somewhere in between. **Karl Schwarzschild**, **Edward Milne**, and **Arthur Eddington** appear elsewhere in this book.

Schuster was the son of a Frankfurt textile merchant and banker. In the wake of the 1866 "seven weeks war" when Frankfurt was annexed by Prussia, the family moved to Manchester, England. Schuster was educated privately and at the Frankfurt Gymnasium. He attended the Geneva Academy from 1868 until he joined his parents at Manchester in 1870. Schuster studied physics at the Owens College, Manchester, and the University of Heidelberg, where he obtained his doctorate in 1873.

After a few years at the Cavendish Laboratory in Cambridge (1875–1881), Schuster returned to Manchester to become professor of applied mathematics (1881–1888) and later professor of physics (1889–1907). After an early retirement at the age of 56, he spent his time with his own research and on the formation of the International Research Council. With his retirement, Schuster made way for **Ernest Rutherford**.

Schuster worked in many areas, many of them related to astronomy:

Spectroscopy. In 1881, Schuster refuted the speculation of **George Stoney** that spectral lines could be regarded as harmonics of a fundamental vibration. He did this using a statistical analysis of spectral lines of five elements. Schuster concluded: "Most probably some law hitherto undiscovered exists which in special cases resolves itself into the law of harmonic ratios." In 1888, **Johann Balmer** took a fairly large step forward when he delivered a lecture to the Naturforschende Gesellschaft in Basel. He represented the wavelengths λ of the spectral lines as $\lambda = h \cdot m^2/(m^2 - n^2)$, where m and n are integers. For the hydrogen atom, where $n = 2$, it would lead to wavelengths $h \cdot 9/5$, $h \cdot 16/12, h \cdot 25/21$ …, the Balmer Series seen in the visible. While Schuster had not yet seen this, his statistical analysis had refuted the speculation of a law $\lambda = h\dot{c}m$, which Stoney had proposed. The Balmer law $1/\lambda = R \cdot (1/m^2 - 1/n^2)$ would later be derived by quantum mechanics.

Schuster's most notable paper, on the analysis of stellar absorption features, was not published until 1905.

Electricity in gases. Schuster was the first to show that an electric current is conducted by ions (charged particles). He also showed that the current could be maintained by a small potential once ions were present. He was the first to indicate a path toward determining the charge–mass ratio e/m for cathode rays by using a magnetic field. This method would ultimately lead to the discovery of the electron.

Terrestrial magnetism. Schuster's study of terrestrial magnetism showed that there are two kinds of daily variations in the magnetic field of the Earth – atmospheric variations caused by electric currents in the upper atmosphere as well as internal variations due to induction currents in the Earth. The Schuster–Smith magnetometer is the standard instrument for measuring the Earth's magnetic field. Schuster's numerous articles examined and rejected many proposed theories of geomagnetism, usually because of shortcomings in their mathematics or physics.

X-rays. In 1896, Wilhelm Röntgen had sent copies of his manuscript to a small group of fellow scientists – Schuster in Manchester, Friedrich Kohlrauch in Göttingen, Lord Kelvin (**William Thomson**) in Glasgow, **Jules Poincaré** in Paris, and Franz Exner in Wien. In the same year, Schuster proposed that the new X-rays of Röngten were, in fact, transverse vibration of the ether of very small wavelength, that is, a short-wavelength extension of the radiation (light) implied by Maxwell's equations.

Antimatter. Schuster published two letters on antimatter in *Nature* in 1898. In them, he surmised "if there is negative electricity, why not negative gold, as yellow as our own?" For 30 years, Schuster's conjecture gathered dust. Only in 1927, did an equation by Paul Dirac predict an oppositely changed counterpart to the electron.

Expeditions. Schuster, having been invited by **Norman Lockyer** to join an expedition to Siam in 1875, to observe a total eclipse, was then asked by **George Stokes** to take charge of the whole expedition on behalf of the Royal Society. In the 19th century, some, if not all, of the world's astronomers believed in a planet inside the orbit of Mercury. This speculative intra-Mercurian planet was called Vulcan. Only a total solar eclipse would make possible seeing it.

The planet Vulcan had been a theoretical construct to solve a problem in planetary dynamics – the mystery of Mercury's orbit. This problem was only resolved in 1915 with **Albert Einstein**'s general theory of relativity, in which the orbital deviations could be explained due to relativistic effects of the Sun's huge mass bending space-time. Vulcan does not exist, and never did; the hunt for it was finally abandoned after the total solar eclipse of 1929.

No eclipse yielded an intra-Mercury planet. But Schuster photographed a comet during the total solar eclipse of 1882.

Laboratory. Schuster raised funds to construct a new laboratory in 1897 and created new departments, including a department of meteorology in 1905.

Schuster was the first secretary of the International Research Council, established under the Treaty of Versailles (which abolished all pre-World-War-I international scientific collaborations) from 1919 to 1928, and was knighted in 1920.

Oliver Knill

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Schwabe, Samuel Heinrich

Born **Dessau, (Sachsen-Anhalt, Germany), 25 October 1789**
Died **Dessau, (Sachsen-Anhalt), Germany, 11 April 1875**

As an amateur lunar, planetary, and especially solar observer, Samuel Schwabe is best known for his discovery of the 11-year sunspot cycle. Schwabe was raised in a scientifically oriented home; his father was a prominent physician, while his maternal grandfather was a pharmacist named Haeseler. Apparently influenced by his grandfather, in 1806, Schwabe began an apprenticeship in a pharmacy in his hometown. During his later pharmaceutical studies in Berlin, he developed a lifelong interest in botany and took his first courses in astronomy.

After his grandfather's death in 1812, Schwabe took over the family pharmacy and became wealthy. He acquired a telescope from a lottery in 1825, recording his first observation of the Sun on 30 October that same year. Acting on the suggestion of **Karl Harding**, Schwabe at first scoured the solar disk in search of an intra-Mercurial planet in transit across the Sun. However, his interest gradually changed to keeping records of sunspots, which he observed every day, whenever the weather at Dessau permitted. Schwabe soon outgrew his first telescope; in 1826 he acquired the 4.8-in. Fraunhofer refractor used by **Wilhelm Lohrmann** to map the Moon until his eyesight failed.

By 1829, Schwabe's interest in astronomical research so absorbed him that he no longer had time for or interest in the pharmacy. He sold it and devoted the rest of his life to research. By 1843, he had still not discovered an intra-Mercurial planet – this is hardly surprising since none exists. However, Schwabe's sunspot data, which had been accumulated through two sunspot maxima and two minima, led him to suspect the existence of a cyclical pattern, with a period of about 10 years. Schwabe was slow to publish; his first announcement, a letter to **Heinrich Schumacher**, printed in the *Astronomical Nachrichten* (no. 495), was almost completely ignored. Clearly, as solar historian Karl Hufbauer suggests, "he was too far outside the astronomical mainstream to receive the attention that, in retrospect, he deserved."

Schwabe was basically a compulsive observer and collector, rather like his great contemporary **Johann Schmidt**. During the period when he was most active as an amateur astronomer, Schwabe was also involved as founding member and president of a local society for natural history, to which he contributed many specimens of plants and minerals. He published a two-volume work, *Flora Anhaltina*, in 1838 in which he described more than 2,000 plants.

Meanwhile, the great German scientist, **Alexander von Humboldt**, presented Schwabe at court. The discovery of the sunspot cycle at last began to take hold after Humboldt publicized Schwabe's work in his celebrated *Kosmos* (1851). Acceptance of the sunspot cycle's reality by astronomers was assured after **Edward Sabine** of the Royal Society (London) and **Johann Wolf** of the Bern Observatory independently noted the correlation between Schwabe's records of sunspot numbers and variations in terrestrial magnetism. Although studied since the 1830s, magnetism was just then being subjected to systematic analysis for the first time. Wolf's reduction of sunspot observations since **Galileo Galilei**'s time indicated a periodicity of 11 years, rather than Schwabe's suggested 10 years.

In recognition of his sunspot work, Schwabe received the Gold Medal of the Royal Astronomical Society [RAS] in 1857. It was presented to him by the well-known British discoverer of solar flares, **Richard Carrington**, in Dessau. This honor made Schwabe something of an anglophile, and accounts for his decision to bequeath his 31 volumes of drawings and observational notes dating from 1825 to 1867 to the RAS. Schwabe was elected to the membership in the Royal Society of London in 1868.

In addition to the Sun, Schwabe was always an avid observer of the Moon and planets. On 5 September 1831, he made the first drawing to indicate clearly the presence of the Great Red Spot Hollow since the observations of **Giovanni Cassini** and his nephew **Giacomo Maraldi** in the late 17th and early 18th century. Interestingly, Schwabe equated the Jovian spots with sunspots, even claiming to see sunspot-like penumbrae surrounding the Jovian spots. However, in contrast to his sunspots, Schwabe never succeeded in reconciling the Jovian spots to any kind of regularly recurring cycle.

Schwabe's observing notebooks and sketches are maintained in the RAS archives at Burlington House, London.

William Sheehan

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Schwarzschild, Karl

Born **Frankfurt am Main, Germany, 9 October 1873**
Died **Potsdam, Germany, 11 May 1916**

German theoretical astrophysicist Karl Schwarzschild is eponymized in the Schwarzschild solution to the equations of general relativity, the Schwarzschild horizon around black holes implied by that solution, and a number of other concepts in astrophysics. He was the eldest of seven children of Moses Martin Schwarzschild, a successful member of the Frankfurt business community, whose ancestors can be traced back in the city to the 16th century, and Henrietta Sabel. One of his sisters married **Robert Emden**. Karl Schwarzschild married Else Rosenbach in 1909. They had three children, Agatha (later Thornton, a classicist whose later career was spent in New Zealand), **Martin Schwarzschild**, and Alfred (who remained in Germany into World War II).

Schwarzschild first attended the Jewish community school, and completed the *Arbitur* degree in 1891 at the municipal gymnasium in Frankfurt. He began studying astronomy at the Kaiser Wilhelm University in Strassburg, and, after a year of military service (1893/1894) in Munich, completed his Ph.D. in 1896 with **Hugo von Seeliger** at the Ludwig Maximilian University. Schwarzschild's first job was as an assistant to Leo de Ball at Kuffner Observatory in Vienna (1896–1899), and his second at Munich as a university lecturer.

In 1901, Wilhelm Schur, the director of the Göttingen Observatory, died. After Seeliger and **Maximilian Wolf**, Karl Schwarzschild was third on the recommendation list. Neither Seeliger nor Wolf wanted to go to Göttingen. Schwarzschild was next, but in the beginning the ministry in Berlin did not want to have him as director and full professor at this post. Two more candidates were asked, who also declined. On 10 October 1901, Schwarzschild sent

his parents a telegram, which read, "Extraordinarius and Director. Arrive Monday – Karl." By 24 May 1902, he was appointed to a full professorship.

Much of Schwarzschild's work of lasting importance to astrophysics dates from the Göttingen period. Papers published in 1906 established how stars could exist stably with energy carried entirely by radiation (as first suggested by **Ralph Sampson** in 1894), established the concept of local thermodynamic equilibrium (meaning that the same temperature described the gas and the radiation in a given volume, but that radiation could flow systematically in one direction), and developed the Schwarzschild criterion for deciding when radiation could no longer carry all the energy so that convection would set in, giving rise, for instance, to the observed granulation of the solar surface. He also analyzed the aberrations in various kinds of telescopes.

Schwarzschild also considered the question of how to determine the distances of stars too far away to have measurable parallaxes, arriving at theoretical justification for a method that used only apparent brightnesses and motion across the plane of the sky. He then asked how one might best describe the motions of large numbers of stars through space, arriving (1907/1908) at an alternative to the star streams of **Jacobus Kapteyn**. Schwarzschild's velocity ellipsoid recorded the fact that the dispersion of velocities seemed to be largest in two opposite directions in the sky, next largest in a direction perpendicular to that, and smallest in the third perpendicular direction. These directions are now understood as projections of the rotation of the Milky Way Galaxy and the motions of the stars perpendicular to the galactic plane. Of his students at Göttingen, the one whose work connects most directly with modern astronomy was **Hans Rosenberg**, who, on Schwarzschild's advice, plotted the luminosity of members of the Hyades as a function of their spectral type, thereby publishing in 1910 what later became known as the Hertzsprung–Russell diagram.

In 1909, Schwarzschild was appointed successor of **Hermann Vogel** at the Astrophysical Observatory at Potsdam. Although this was the most prominent position that an astronomer could hope to hold in Germany at that time, Schwarzschild was not at all enthusiastic. His wife's family lived in Göttingen, he had a wide circle of friends, and, above all, Göttingen was a mathematical stronghold. Nevertheless he finally agreed, with the condition that his assistant **Ejnar Hertzsprung** should move to Potsdam with him. Schwarzschild quickly familiarized himself with the various fields of work being carried out at Potsdam. In 1910, he traveled to the United States to attend a meeting of the American Astronomical Society and used the opportunity to visit many of the large American observatories. He returned convinced that Germany definitely needed an observatory in the Southern Hemisphere. Schwarzschild proposed Windhoek, in German South-West Africa.

Schwarzschild's research at Potsdam included additional calculations of stellar atmospheres, including the reversing-layer (or Schuster–Schwarzschild) approximation for how absorption lines are produced in stellar atmospheres, permitting calculation of how much of each element must be present. Other papers reported a study of how dark absorption lines and continuous radiation should appear as a function of position on the solar disk and the fraction of energy carried by convection. He also analyzed observations of the tails of the two great comets of 1910 (C/1910 A1 and 1P/Halley), showing that the tails contain material extraordinarily tenuous even compared to thin air. And Schwarzschild began applying the atomic model of **Niels Bohr** to the analysis of spectra of atoms and simple molecules.

In 1914, World War I broke out and affected the work of the institute more and more. Schwarzschild immediately volunteered for service in the army. In September 1914, he was sent, as acting officer, to Namur in Belgium as head of a field weather station. The whole of 1915 he spent in the field, first in Belgium, later as a member of the artillery staff partly in France and Russia. During the Russian campaign, Schwarzschild already showed symptoms of pemphigus, a painful and then incurable skin disease (now recognized as having an autoimmune component). He was invalided home, hospitalized, and died soon after.

The year of Schwarzschild's death saw the publication of three significant papers – one on ballistics (part of his war work), one explaining the broadening of atomic lines in the presence of an external electric field (the Stark effect, discovered in 1913), and the classic description of the structure of space-time outside a spherically symmetric distribution of mass (or point mass) in the framework of the general theory of relativity, which introduced the concepts of the Schwarzschild radius and Schwarzschild horizon.

Schwarzschild received many outstanding honors and awards. Some of the most important are ordinary member of the Königliche Gesellschaft der Wissenschaften at Göttingen (1905), associate of the Royal Astronomical Society, London (1909), member of the Kaiserlich Leopoldinisch-Carolinsche Deutsche Akademie der Naturforscher (1910), and member of the königlich-preussischen Akademie der Wissenschaften in Berlin (1912).

Peter Habison

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Schwarzschild, Martin

Born **Potsdam, Germany, 31 May 1912**
Died **Langhorne, Pennsylvania, USA, 10 April 1997**

Martin Schwarzschild put 20th-century understanding of stellar structure and evolution on a firm, quantitative footing by calculating the solutions to the differential equations that describe stellar physics for a range of star masses and compositions. He did so using realistic descriptions for nuclear reactions and energy transport, and evolving those solutions forward in time to reveal the effects of gradual composition changes due to the nuclear reactions. Schwarzschild also made significant contributions to the definition of stellar populations and to observations and theory of solar and stellar convection. Late in his career, Schwarzschild attempted to put the dynamical structure and evolution of elliptical galaxies on a similarly firm numerical footing.

Schwarzschild was the second child and elder son of **Karl Schwarzschild** and Else Rosenbach, the gentile daughter of a local surgeon. Martin was born in Potsdam while his father was director of the Astrophysical Observatory there. **Robert Emden**'s wife was his paternal aunt. After the death of Martin Schwarzschild's father in 1916, the family returned to Göttingen, where Martin was educated in the Gymnasium. Family friends **Carl Runge**, the numerical analyst, and Ludwig Prandtl, a pioneer in aerodynamics, guided his early studies.

Schwarzchild began work at the Göttingen University, initially in mathematics under Richard Courant. That early background provided a foundation for his later grasp of the problems of numerical solution of the nonlinear, coupled differential equations that describe stellar structure, including what is called the Courant condition (that one must not try to take time steps in an evolutionary calculation that are longer than the time required for a sound wave to cross the narrowest zone across which interior conditions change significantly). After one semester in Berlin, Schwarzschild turned to astronomy, completing a doctoral thesis in December 1935, under **Hans Kienle**. His work had initially dealt with observations of Polaris, but he switched to theory of pulsating stars when it became clear that it would be wise for him to leave Germany as quickly as possible.

After a brief stop at Leiden Observatory to meet his father's former friend and colleague **Ejnar Hertzsprung**, Schwarzchild gratefully accepted a 1-year (1936/1937) position as a Nansen Fellow, working with **Svein Rosseland** in Oslo, Norway. There, he completed the publication of his thesis and wrote on the then-puzzling problem of the source of stellar energy.

With the support of both director **Harlow Shapley** and **Cecilia Payne-Gaposchkin**, Schwarzschild received a 3-year Littauer Fellowship at Harvard College Observatory. While there, he worked on the light curves of Cepheid variables and other variable stars and met graduate student Barbara Cherry (BA, Radcliffe College) who became his wife in 1945.

Schwarzschild's first academic appointment was at Columbia University and Rutherfurd Observatory (lecturer in astronomy: 1940–1944, and assistant professor 1944–1947) under director Jan Schilt. There he published papers touching on stellar pulsation, convection, and rotation. He also worked on a new photometer and, foreshadowing the work for which he would be best known, on the use of punch-card machines to integrate differential equations.

Schwarzschild's term at Columbia University was interrupted by service in the United States Army, where he qualified for Officers' Candidate School after becoming a United States' citizen in 1942. He served in an army intelligence unit in Italy where his German accent (conspicuous to the last and much imitated affectionately by his students and colleagues) occasionally caused some confusion.

In 1947, Schwarzschild accepted a position at Princeton University, where stellar astronomy had been badly damaged by the retirement of **Henry Norris Russell**. The university wisely offered positions simultaneously to **Lyman Spitzer** and Schwarzschild; each regarded the other's presence as a major incentive for accepting the appointments. They remained friends and colleagues for 50 years, dying within less than 2 weeks of each other.

Schwarzschild made significant advances in three areas of astronomy. First was stellar populations, the recognition that kinematic and photometric classes identified by **Walter Baade** have associated differences in age and composition. A 1950 paper with Barbara Cherry Schwarzschild demonstrated that stars that move rapidly relative to the Sun (population II) are also deficient in heavy elements. Papers published the same year by Nancy Grace Roman and by Wilhelmina Iwanowska made the same point. Moreover, work with Spitzer, published the next year, was on the forefront in pointing out that the formation of population I stars must be an ongoing process.

Second was the numerical calculation of stellar structure and evolution, including the demonstration that red giants must be chemically inhomogeneous and that population II stars must be older than what was then supposed to be the age of the Universe (joint work with **Fred Hoyle** published in 1955). Much of the numerical work tracing the lives of solar-type stars on beyond hydrogen fusion to helium burning and the ejection of planetary nebulae was in collaboration with Richard Härm. Schwarzschild's 1958 monograph, *The Structure and Evolution of the Stars*, served as primary introduction to the field for astronomers for the next 15 or more years.

Third, Schwarzschild was among the first to recognize the importance of convection in stellar structure and evolution and its relationship to solar granulation. In due course, he assumed primary responsibility for a project, called Stratoscope I, in which a balloon carried a 12-in. telescope to 30 km in order to image the granulation with sufficiently good angular resolution to demonstrate that the granules were truly convection cells. Stratoscope II, with a 36-in. mirror, brought back near-infrared spectra and images of Mars, cool stars, and several galactic nuclei. Schwarzschild predicted in 1975 that the convection cells on red giants would be very large, which was eventually shown to be true in Hubble Space Telescope images of Betelgeuse.

From 1976 onward, most of Schwarzschild's work focused on the structure of elliptical galaxies. His approach was to require that the integrated gravitational contribution of all the stars in their orbits add back up to correspond to the gravitational potential in which the orbits were calculated. This work continues, in the hands of more than a dozen younger astronomers, his students and postdoctoral fellows. Schwarzschild advised a total of 23 Ph.D. students at Princeton University and several at Columbia University.

Schwarzschild was elected to the academies of science of Belgium, Norway, and Denmark, as well as the United States; held honorary D.Sc.s from Swarthmore, Columbia, and Princeton universities; and was the recipient of the United States National Medal of Science (posthumously), the Bruce Medal of the Astronomical Society of the Pacific, the 1994 Balzan Prize (shared with Hoyle), the Karl Schwarzschild Lectureship of the Astronomische Gesellschaft (those lectures being his only publications in a German journal after his 1935 departure), the George Darwin Lectureship of the Royal Astronomical Society, the Russell Lectureship of the American Astronomical Society, and membership in the Royal Society, London.

Schwarzschild was vice president of the International Astronomical Union. His partially overlapping terms as vice president and president of the American Astronomical Society [AAS] (1968–1972) were of particular importance in the history of American astronomy because he oversaw the transfer of ownership of the most prestigious publication in the field, the *Astrophysical Journal*, from the University of Chicago to the AAS. Schwarzschild was also instrumental in preventing the breakup of the Society when workers in solar physics, high-energy astrophysics, and planetary science came to feel that the AAS was no longer serving their needs. His solution, semi-autonomous divisions, has continued to serve to the present.

Schwarzschild was keenly aware of the responsibility of the scientific community to communicate the excitement and importance of science to the rest of society and took the position that projects like Apollo, even if their scientific yields were modest, were nevertheless justified as a source of inspiration for science education and technology.

Schwarzschild's papers are largely archived at Princeton University, but a couple of interesting items concerning his departure from Germany are in the Swarthmore College Library. References to many of his most important publications are found in the obituaries by Mestel (1999) and Trimble (1998).

Virginia Trimble

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Schwassmann, Friedrich Karl Arnold

Born **Hamburg, (Germany), 25 March 1870**
Died **Hamburg, (Germany), 19 January 1964**

German observational astronomer Friedrich Schwassmann, eponymized in several comets, graduated in 1891 after studies at Leipzig, Berlin, and Göttingen universities. He initially held short-term appointments at the observatories in Potsdam (1893–1895), Göttingen (1896/1897), and Heidelberg (1897–1901), where he worked under the supervision of **Maximilian Wolf**. Schwassmann spent the next 2 years at the institute for testing of chronometers of the German Maritime Observatory, and the rest of his life connected with the observatory in Hamburg–Bergedorf. He was appointed as an observer in 1902 and retired in 1934, but continued work as a volunteer for the next 25 years and frequently attended seminars and lectures at the observatory.

Schwassmann is remembered largely for the comets he discovered together with his younger assistant **Arno Wachmann** from 1927 onward, including three short-period comets – 29P/1927 V1, 31P/1929 B1, and 73P/1930 J1—that each carry the name Schwassmann–Wachmann. He also discovered a couple of minor planets (at Heidelberg, with Wolf). Schwassmann's most extensive work at Hamburg–Bergedorf consisted, first, of observations of nebulae and star clusters for the second index catalogue of **John Dreyer** and, later of observations of accurate positions of stars from the selected areas of **Jacobus Kapteyn** using a double astrograph.

Martin Solc

Selected Reference

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Scot, Michael

Born **possibly the Borders of Scotland, *circa* 1175**
Died **possibly the Borders of Scotland, *circa* 1234**

Michael Scot's main contribution to astronomy was through his translations of works from Arabic into Latin, including those by **Al-Bitruji** and **Aristotle**, and significantly **Ibn Rushd**'s *De motibus* *coelorum*. Scot was thus instrumental in reintroducing Aristotelian ideas to the Western world.

Scot traveled widely around Europe, serving as court astronomer and physician (or astrologer and alchemist) to Holy Roman Emperor Frederick II. Legends of his supernatural powers abound (popularized by **Dante Alighieri**, Giovanni Boccaccio, and Sir Walter Scott), and few facts are known about his life.

Douglas Scott

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Scottus [Scotus] Eriugena, Johannes [John]

Flourished **(France), 9th century**

Johannes Scottus Eriugena was a scholar of the Carolingian Renaissance. His most famous astronomical work is a commentary on that of **Martianus Capella**. The claim that Eriugena's model of the Sun, stars, and planets anticipates the Tychonic system is controversial.

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Seares, Frederick Hanley

Born **near Cassopolis, Michigan, USA, 17 May 1873**
Died **Honolulu, Hawaii, USA, 20 July 1964**

American photometrist Frederick Seares was responsible for a large fraction of the work of measuring accurate apparent brightnesses of stars as part of a multi-observatory project to understand the distribution of stars in the Milky Way. He was the son of Isaac Newton Seares and Ella Ardelia (*née* Swartwout) Seares, and, after two family moves to Iowa and California, received his BS in 1895 from the University of California (Berkeley). The university later awarded Seares an LLD, and he also had an honorary degree from the University of Missouri.

Seares obtained a position of instructor at the University of California and married Mabel Urmy. Soon, though, he decided to continue his education in Europe, studying first at the University of Berlin for a year and then at the Sorbonne in Paris for another year. Seares then returned to the United States with his family to take a position of professor of astronomy at the University of Missouri, in Columbia, where **Harlow Shapley** was among his undergraduate students. Seares spent 8 years as the director of the university's Laws Observatory. He managed to make a number of improvements at the observatory, both in the quality of equipment and in the quality of the research efforts, and was able to influence a number of students including Shapley.

In 1909, **George Hale** brought Seares to the Mount Wilson Observatory as the new head of the Computing Division. More significant for Seares was that he was given editorial control over the observatory's publications along with his astronomical duties. These tasks put Seares in regular contact with many of the astronomers of his time, through correspondence and cooperation in joint research and publication, and he served as one of the editors of the *Astrophysical Journal* from 1927 to 1941. Many colleagues gratefully allowed the meticulous Seares to edit their work to the point of complete rewriting.

Seares was part of the United States delegation to the 1919 and 1922 conferences in Brussels and Rome that established the International Research Council (later International Council of Scientific Unions) and the International Astronomical Union [IAU].

An early research interest for Seares, which would stay with him throughout his career, was astronomical photometry. With Seares's international experience he began an involvement with the Dutch astronomer **Jacobus Kapteyn**, and his statistical efforts to determine the shape and size of the galaxy (then widely thought to constitute the whole Universe) by using detailed studies of 252 "Selected Areas" of the sky. Seares's interest was in establishing photographic–photometric standards that would provide accurate magnitude estimates for the stars in the Selected Areas. He would play a major role in establishing the magnitudes of the stars in Selected Areas 1–139. In participating in this effort, Seares would work with a number of the world's leading astronomers and lead the primary effort for constantly refined accuracy in this work.

In 1922, Seares was elected the first president of the Commission on Stellar Photometry of the IAU. For the next several decades, his work would provide the standard in stellar photometry. He also would rise to the position of assistant director at the Mount Wilson Observatory by 1925. A 1931 paper by Seares was one of the first extensive efforts to incorporate the effects of absorption by interstellar dust (discovered in 1930 by **Robert Trumpler**) in the analysis of stellar statistics.

Seares received the Bruce Medal of the Astronomical Society of the Pacific in 1940 for his work "in determining fundamental standards" in astronomy, having previously served the society for two terms on their board of directors and one as president.

Following his official retirement, Seares was appointed a research associate at Mount Wilson from 1940 to 1946 and became largely inactive in astronomy after that period. Much of his work on photometric standards has been replaced over the years by photodectric methods developed by astronomers that followed him. This, of course, would have been most pleasing to the man who always strove to obtain the highest quality in the information he published.

Richard P. Wilds

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Secchi, (Pietro) Angelo

Born **Reggio nell'Emilia, (Emilia Romagna, Italy), 18 June 1818**
Died **Rome, Italy, 26 February 1878**

A pioneer in the study of the physical characteristics of celestial bodies, Pietro Angelo Secchi, S. J., observed spectra of the stars, classified more than 4,000 of them according to a scheme he devised, and made important studies on the physical constitution of the Sun. His achievements, during the 1860s and 1870s, contributed to the rapid growth of astrophysics as a new way of studying the heavens.

Secchi's parents, who aimed to give their son an education fit for his quick mind, had him attend the Jesuit Gymnasium in his hometown. He was only 15 when he became a Jesuit novice in Rome. There, he devoted himself to the study of classical literature, philosophy, and the exact sciences. While deeply interested in all fields of knowledge, Secchi soon showed a greater concern for science. From 1841, he taught physics at Loreto College. His scientific interests came to encompass mathematics, astronomy, magnetism, chemistry, optics, and so forth.

In 1845, he was called to Rome to study theology and was ordained in 1847. The following year, as a result of the expulsion of the Jesuits from Rome, Father Secchi took refuge at the Jesuits' Stonyhurst College in England, and in Georgetown, near Washington, District of Columbia, USA. He became an assistant at the latter observatory, where he improved his astronomical knowledge. In 1849, upon the readmission of the Jesuits to Rome, Secchi returned there, and, in 1850, Pope Pius IX appointed him as director of the Collegio Romano Observatory, replacing **Francesco de Vico** who had died while in exile at London.

One of Secchi's first tasks was to upgrade the equipment and oversee the relocation of the college's observatory. He first acquired a 9.5-in. Merz refractor, identical in size to that used at Dorpat by **Friedrich Struve**, for the continued observation of binary stars. Over the next 7 years, he completed nearly 1,300 measurements of double stars. Secchi's devotion to the newer physical astronomy was a choice dictated in part by the structural limitations of the observatory. Its location in the tower of the Jesuit Church of San Ignacio made it difficult to conduct precise positional measurements of stars necessary for the preparation of an astrometric catalog. Despite the modest equipment at his disposal, Secchi used it to the utmost in coming years.

By employing the analytical techniques of **Robert Bunsen** and **Gustav Kirchhoff**, Secchi began to investigate the stars with a spectroscope in 1863, and in that year, proposed a scheme of spectral classification. He initially subdivided stars into two classes, consisting of yellow or red (colored) stars, and white stars. Although the discriminating criterion was nominally the star's color, Secchi came to associate colors with more definite spectral characteristics and founded his classification scheme upon the latter. By 1866, he had identified a third class and by 1868, announced four principal Secchi types of stellar spectra. These were characterized as follows.

Type I: White or blue-white stars (*e. g.*, Sirius, Vega), whose main spectral features were a few strong absorption lines, attributed by Secchi to hydrogen.

Type II: Yellow stars (*e. g.*, Sun, Arcturus) with more numerous, narrow absorption lines. While still visible, the hydrogen lines were less intense.

Type III: Orange or red stars (*e. g.*, Betelgeuse, α Her), with spectra having wide, dark bands and a maximum intensity on the red side. The majority of stars observed belonged to these three types, which he ordered according to the criterion of increasing complexity.

Type IV: Very red stars (*e. g.*, 19 Piscium), whose spectra showed dark bands but with conspicuous differences from Type IIIs. Secchi observed that these spectra were similar to the inverted (*i. e.*, flame) spectrum of carbon; he had discovered the carbon stars.

Type V: A rare type (*e. g.*, γ Cassiopeia), with bright *emission* lines, was announced in 1877.

This scheme was adopted in *Le Stelle* (The Stars), published by Secchi in 1877, representing a culmination of his studies in stellar spectroscopy. His classification of the spectra of some 4,000 stars represents his major contribution to stellar astrophysics. The system was employed by astronomers for roughly 50 years until superseded by the Harvard classification system. Central to Secchi's achievement was his notion that the enormous diversity of stellar spectra could be reduced to a classification scheme employing just a few basic types.

Secchi offered a qualitative interpretation of the features he observed in stellar spectra. He guessed that stellar temperatures could be the physical parameter most responsible for the differences seen in their spectra. By comparing stellar and laboratory spectra, Secchi identified hydrogen as the element whose strong lines were found in the Type I stars. He supposed that their widths could be related to the pressures existing in the stars' outer layers.

The other field of research in which Secchi made important contributions was solar physics. Secchi studied numerous phenomena on or above the Sun's surface. During the total solar eclipse of 18 July 1860, he observed and photographed the Sun's corona and prominences. By comparing his results with those obtained by **Warren de la Rue**, some 250 miles away, Secchi convincingly demonstrated that those features physically belonged to the Sun and were neither optical effects nor due to an atmosphere of the Moon, as some astronomers had argued.

In subsequent years, Secchi regularly observed solar prominences outside of the times of eclipse, by employing the spectroscopic technique originally developed by **Pierre Janssen** and independently by **Norman Lockyer**. From these observations, Secchi proposed a classification of prominences, which he distinguished as "quiescent" and "eruptive", terms still employed today. Secchi likewise studied sunspots, their distribution, and their relationship with prominences. By observing sunspots at various solar latitudes, Secchi determined that the Sun has a differential rotation and behaves more like a liquid than a solid body. He named the bright areas around sunspots "faculae", deduced (correctly) that solar granulation was attributed to the action of convection cells, and measured the effect of limb darkening.

Secchi's solar studies were summarized in *Le Soleil* (The Sun), published in 1875–1877, in which Secchi related the observed surface phenomena to an overall model of the Sun's structure. He took the Sun to be composed mainly of gas and subject to complex circulation, with surface eruptions driven by an unrecognized force (later found to be magnetic fields).

Secchi turned his spectroscope onto the planets, comets, meteors, and nebulae. He provided an early classification of the latter as "planetary," "elliptical," and "irregular." Secchi argued for the existence of an interstellar medium as the cause of those dark lanes extending the length of some nebulae especially the Andromeda Nebula.

To coordinate and communicate those spectroscopic observations made by astronomers, Secchi, **Lorenzo Respighi**, and **Pietro Tacchini** founded, in 1871, the Società degli Spettroscopisti Italiani, the first scientific society expressly devoted to astrophysics.

Secchi was concerned with other scientific subjects, including geodesy and meteorology. He invented a "meteorograph," a device able to record the time variations of atmospheric temperature and pressure on a moving sheet of paper. It was shown at the 1867 Paris Universal Exhibition and was awarded the Grand Prize, conferred upon Secchi by Napoleon III.

After the Franco–Prussian War, when Italian nationalist troops occupied Rome and the Vatican, Secchi remained loyal to the Pope, spending the next 8 years with him as a voluntary prisoner. His own death occurred only three weeks after that of the Pope.

Davide Cenadelli

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See, Thomas Jefferson Jackson

Born **near Montgomery City, Missouri, USA, 19 February 1866**

Died **Oakland, California, USA, 4 July 1962**

American astronomer T. J. J. See is remembered, if at all, for erroneous, perhaps even fraudulent, claims for the detection of planets orbiting other stars, though others of his once wild-sounding ideas sound superficially like our modern understanding of, for instance, solar-system formation. See earned his undergraduate degree from the University of Missouri at Columbia in 1889 and his doctorate from the University of Berlin in 1892 with a thesis on the orbits and origins of visual binary stars. Upon returning to the United States, he spent 3 years at the University of Chicago. While there, he ran afoul of **George Hale**, the driving force behind the establishment of the Yerkes Observatory (and later those at Mount Wilson and Palomar), a circumstance that did little to advance See's career. See spent the next 2 years in the employ of **Percival Lowell**, during which time the former directed a survey of southern double stars as observed from Mexico. In this case, as in most cases during his career, See was a cause of contention, later being accused of falsifying observations.

In 1899, See was appointed a United States Navy professor of mathematics, a rather senior post for so young a man, probably due to the influence of fellow Missourian Champ Clark, a powerful member of the United States House of Representatives. See spent the next 3 years at the United States Naval Observatory, followed by a year teaching mathematics at the Naval Academy. Finally, See was transferred to the Naval Observatory at Mare Island, California, in 1903, and he stayed there until retirement in 1930. The Mare Island Observatory was a dead end, for there were no instruments capable of serious astronomical research. See was the only astronomer there, and his primary duty was related to chronometers. Moreover, he had little interaction with other astronomers, whether in the Bay Area or elsewhere.

See's early work on double stars was generally regarded as good, but he soon began to make dubious and outlandishly inflated claims for his researches on a wide variety of subjects. See's report of visual detection of planetary companions to nearby stars was published only in *Atlantic Monthly* and must have arisen entirely from his imagination. But his orbit for a planet around the secondary star of the visual binary 70 Ophiuchi appeared in the *Astronomical Journal* in 1896 and looks very much like it might have come from real data. Curiously the same star was one of those for which there were erroneous reports of planetary detections in the 1940s. In 1899, **Forest Moulton** demonstrated that See's invisible companion in the 70 Ophiuchi system did not exist; the latter's intemperate response to this refutation caused him to be banned from the pages of the *Astronomical Journal*. Later, in 1912, Moulton showed that parts of See's "capture theory" of planetary formation had, in fact, been "captured" from previously published work of Moulton's. Such peccadilloes ended See's career as a professional astronomer, and he was ostracized from most professional publications (a most unusual circumstance). Although conscientious in his own way and incredibly industrious, he toiled on alone, secure in his belief that he was one of the greatest (and least appreciated) scientists of all time –"The American Herschel" and "The Newton of Cosmogony."

Because of See's outlandish behavior, his speculations were universally scoffed at, though some of them turned out to be correct (generally not for the reasons he suggested). The most startling example was his assertion that lunar craters were due to impacts and not due to volcanism, which was the accepted theory at the time (though both ideas can be traced back very far). In that connection, See had experiments performed with projectiles fired from naval guns, resulting in miniature craters complete with central peaks. Moreover, he stated that all bodies in the Solar System that have solid surfaces carry similar scars, a prediction that has been amply confirmed.

In other areas, See believed that the orbits of the major planets are so nearly circular because of the effects of a resisting medium during their formation, but his circularizing medium was the "luminiferous ether," which he was still claiming as one of his scientific interests into the 1930s, long after the Michelson–Morley experiment had shown that no such medium exists. He also said that mountain ranges are not elevated because the Earth is cooling and shrinking. Both suggestions were considered outlandish at the time made, but not now.

In recent decades, See has become somewhat of an icon for a segment of planetary astronomers. See was an incredibly enthusiastic joiner of scientific societies (arguably to bolster his fading reputation) and belonged to at least 25 societies in astronomy, mathematics, seismology, and physics in at least five countries.

Ronald A. Schorn

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Seeliger, Hugo von

Born **Biala (Bielsko-Biala, Poland), 23 September 1849**
Died **Munich, Germany, 2 December 1924**

Hugo von Seeliger pioneered the use of stellar statistics to derive an improved understanding of the distribution of stars in our Milky Way Galaxy. Son of the mayor of Biala, Seeliger studied physics, mathematics, and astronomy at the universities of Heidelberg and Leipzig. After writing his Ph.D. thesis under **Karl Bruhns** in 1871, he gained his first practical experience as assistant in Leipzig and, from 1873 to 1878, as observer at the Bonn Observatory, directed by **Friedrich Argelander**. Hugo von Seeliger took part in their observations for the great zone catalog of the Astronomische Gesellschaft and joined an expedition to the Auckland Islands in 1874 to observe the transit of Venus. From 1878 to 1881, he was a *Privatdozent* (lecturer) at the University of Leipzig, before he became director of the Grand-Ducal Observatory in Gotha, succeeding **Peter Hansen**.

From 1882 on, Seeliger was full professor of astronomy and director of the Munich Observatory, where he succeeded **Johann von Lamont**. Working conditions at Munich were so satisfactory that he refused later calls to Prague, Strasbourg, Vienna, and Potsdam. During his tenure in that post, Seeliger turned Munich into a major center of astronomical training. **Karl Schwarzschild** was his most prominent student. From 1896 to 1921, Seeliger was president of the Astronomische Gesellschaft, and from 1918 to 1923 he presided over the Munich Academy of Sciences. He was nominated as a corresponding member of the Prussian Academy of Sciences. In 1885, he married Sophie Stoeltzel; the couple had two sons.

Hugo von Seeliger's main achievement was in the field of stellar statistics. He studied the spatial distribution of stars having the same apparent magnitude in a given part of the sky. Numbers of stars were expected to increase by a factor of 2.5 raised to the 3/2 power (or roughly by a factor of four) per magnitude, if they were uniformly distributed. With increasing distance, r, the volume of space increases with the cube of r, while the luminosity falls with the square of r (a reflection of the inverse-square law). But his statistical studies – derived from the two Bonn sky surveys – only yielded a factor between 2.8 and 3.4, which led him to infer a diminishing number of stars in space far from the Sun. As in **Jacobus Kapteyn**'s independent research on the same topic, also written around 1900, Seeliger devised a lenticular model of the Milky Way, having the Sun close to its center, and a maximum extension in the galactic plane of some 30,000 light years. This model of the Galaxy was widely adopted until significant revisions accompanied **Harlow Shapley**'s determination of the distances to the globular clusters.

When physicist **Erwin Freundlich** began exploring gravitational redshifts as one of three experimentally testable consequences of **Albert Einstein**'s general theory of relativity, Seeliger reacted strongly. In 1916, he documented mathematical errors in one of Freundlich's publications, although his polemics reached far deeper and were meant to demolish Einstein's theory of gravitation. He also published alternative interpretations of the other two effects predicted by Einstein's theory – the precession of Mercury's perihelion, and the apparent slight deflection of star positions visible near the Sun's limb during solar eclipses. Among the predominantly conservative German astronomers, Seeliger, who had already acquired a reputation as a merciless critic, became one of the most outspoken antirelativists.

Classical cosmology is another field in which Seeliger's contributions are remembered. He had noticed that a combination of the Euclidean structure of space, a nonvanishing mean density of matter, and **Isaac Newton**'s law of gravity led to an inherent instability of the strictly Newtonian cosmos. Two decades before the advent of a dynamic (and relativistic) cosmology, this situation appeared inconceivable to him. Thus, he tried to remedy the situation by modifying Newton's law. His reflections on the status of absolute motion in Newtonian mechanics were inspired by his Leipzig mathematics teacher, **Carl Neumann**, who had introduced an alternative concept to Newton's absolute space for the definition of inertial motion.

Other interests of Hugo von Seeliger included theories of the motion of double stars and of star systems containing three or four stars (*e. g.*, ζ Cancri), the spectra of novae (such as τ Aurigae) and their interpretation, physiological optics, the photometry of Saturn's rings and of cosmic dust clouds, the zodiacal light, and anomalous refraction in the terrestrial atmosphere. His colleagues valued his combination of deep theoretical insight, mathematical proficiency, and remarkable skill in practical astronomy. A *Festschrift* honoring his services to astronomy was organized on the occasion of his 75th birthday, which occurred less than 3 months before his death.

Klaus Hentschel

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Seleukus of Seleukeia

Flourished **Seleukia, (Iraq), 150 BCE**

Seleukus appears to have argued for an infinite heliocentric *kosmos*, and was the first to hypothesize a mechanism for the long-known lunar influence on the tides. The precise nature of his theory is hard to determine, because his own writings have not survived.

Seleukus was from the city of Seleukeia, on the Persian Gulf near the mouth of the Tigris and Euphrates rivers, and studied with Mesopotamian astronomers and astrologers. His apparent date is determined from the fact that he responded to Krates of Mallos (who was himself active in the decades around 165 BCE), and he must have preceded **Hipparchus**' *Geography*, composed in the decades around 140 BCE, which responds to his ideas.

Plutarch, in the *Platonic Questions* 8.1, records that Seleukos proclaimed what **Aristarchus** had only hypothesized, that the Earth rotated; since Aristarchus also hypothesized that the Earth orbited the Sun, it is usually assumed that Seleukus did so as well. One ancient objection to a heliocentric theory was the apparent absence of stellar parallax (not in fact observed until 1836 by **Friedrich Bessel**, **Friedrich Struve**, and **Thomas Henderson**), which Aristarchus answered by hypothesizing that the sphere of the fixed stars was large enough to make their parallax imperceptible. Seleukus is known to have argued for an infinite universe on philosophical grounds similar to those earlier advanced by the Pythagorean **Archytas** "if the *kosmos* had a boundary, what would happen if you penetrated it?"

A second major ancient objection to a heliocentric theory was the absence of evidence that the Earth rotated. Seleukus' tidal model held that the rotation of the Earth and the orbital motion of the Moon disturbed the *pneuma* (vital spirit) filling the intervening space, which swelled the ocean (*i. e.*, the tides provide the unambiguous evidence of the Earth's rotation). He argued that when the Moon is over the Earth's Equator, the tides are regular and their irregularity increases in proportion as the Moon is distant from the Earth's equatorial plane. He also noted that the tides differed from sea to sea, and he divided the monthly tidal cycle into seven phases.

Whether or not Seleukus advocated a fully heliocentric system is unclear, but he may be the astronomer responsible for the partly heliocentric epicyclical system recorded by **Theon of Smyrna** and by **Vitruvius**. According to that model, the hollow orbital sphere of Venus encloses that of Mercury, which in turn encloses the solid sphere of the Sun, and those three together orbit the Earth carried on a common hollow sphere.

Paul T. Keyser

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Seneca

Flourished **Rome, (Italy), 1st century**

Roman author Seneca asserted that comets follow fixed paths, thereby anticipating **Edmund Halley**.

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Seng Yixing

➔ **Yixing**

Serviss, Garrett Putnam

Born **Sharon Springs, New York, USA, 24 March 1851**
Died **Englewood, New Jersey, USA, 25 May 1929**

Garrett Serviss's astronomy popularization spanned more than a half-century, sparked when he was a child by viewing the night sky from his father's farm. Clyde Fisher, who would become director of New York City's Hayden Planetarium, wrote that Serviss did "more to popularize astronomy than any one in America, and perhaps in the entire world."

Serviss's parents were Garrett Putnam and Catherine (*née* Shelp) Serviss, whose ancestry can be traced to pre-Revolutionary settlers in the Mohawk Valley. Serviss graduated from Cornell University in 1872 with a science degree, obtained an L.L.B degree from Columbia University in 1874, and was admitted to the New York State bar that year. Instead of practicing law, he chose journalism as a career, becoming a newspaper writer and editor, particularly with the *New York Sun*, for which he wrote a long series of science articles. Serviss resigned from the paper in 1892, took a very successful 2-year "Urania Lectures" tour of the United States, and then continued writing. He joined the American Association for the Advancement of Science and the American Astronomical Society, among others. Serviss was married twice; his first wife, Eleanore Betts died in 1906. His second wife, Henriette Gros Gatier, survived him.

Serviss is perhaps better remembered by science-fiction buffs than by the astronomical community. In retrospect, his entry into that genre was bold indeed, a sequel to H. G. Wells's *War of the Worlds*. The first installment of *Edison's Conquest of Mars* (1898) debuted in the *New York Evening Journal* 6 weeks after the last installment of the serialized Wells classic appeared in *Cosmopolitan* magazine. Nevertheless, Serviss, at best, was a pedestrian writer of science fiction.

In contrast, the several books Serviss wrote for the general public about observational astronomy were extremely well executed and remain worthwhile reading today. The first, *Astronomy with an Opera Glass* (1888; 2nd ed., 1896), was perhaps the best of the lot. The second, Serviss's *Pleasures of the Telescope* (1901), is another gem. The first is a romp through the Northern Hemisphere sky for observers abetted by only minimal optical aid. (Opera glasses were the forerunners of modern binoculars.) The second addresses the exploration of the Universe through what would be regarded at present as very small amateur telescopes. Serviss viewed from Brooklyn, New York, with a 3⅜-in. refractor. The final chapter of *Pleasures* is entitled, "Are there Planets among the Stars?" It seems that Serviss could not resist letting a little speculation spice his otherwise straightforward text.

Leif J. Robinson

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Severin, Christian

Born **Lomborg (Longberg), Jutland, Denmark, 4 October 1562**
Died **Copenhagen, Denmark, 8 October 1647**

Longomontanus, a professor of astronomy and observer, was one of **Tycho Brahe**'s most important students and publicized the Tychonic system in the early 17th century. Christian Severin was born in a poor farmer's family – that of Soeren Poulsen and Maren Christensdatter. After the early death of his father in 1570, he had to work on the farm. During the winter months, Severin received his first tuition from a pastor in Lomborg. Beginning in 1577, he attended the cathedral school of Viborg. At the age of 26, Severin matriculated from the University of Copenhagen, inscribing his name in the Latin form of Longomontanus. Within a year, he began working for Brahe and became his only long-term student, making astronomy his life's work.

After Brahe had left his island of Hven, Longomontanus bade him farewell with a very well-meant letter of resignation dated 1 June 1597. He then continued his studies in Breslau and Leipzig universities. He finally received his MA from Rostock University. In January 1600, Longomontanus again stayed with Brahe in Benatek (close to Prague), where, according to Brahe Special wish, he was supposed to work on the Mars observations. But when **Johannes Kepler** joined Brahe as an assistant, he took over the Mars data, leaving lunar work to Longomontanus. The latter passed his lunar research to Brahe in the summer of 1600 and returned to Denmark.

Back home, in1603, Longomontanus was appointed principal of the Viborg cathedral school, which he had attended as a youth, but retained his interest in astronomy. He corresponded with Kepler on lunar theory. In 1605, he received the professorship for mathematics in Copenhagen, followed by appointment to the chair of "higher mathematics" (*i. e.*, astronomy), a post he held until his death. On the order of King Christian IV, an observatory was erected at the university in 1637. The impressive round tower still stands. There, Longomontanus inaugurated an important observational program to find precise positions for the 777 stars in Brahe's catalog. Although Longomontanus's precision was good, he could not compete with **Christoph Rothmann** working at Kassel Observatory.

Longomontanus has been described as a very easygoing, warmhearted person. In 1607, he married Dorthe Bartholin, sister to the prominent scientist Caspar Bartholin. As a mathematician, he worked on the quadrature of the circle, giving a value for π of $78\sqrt{3}/43$.

Longomontanus's textbook, *Astronomia Danica*, was first published in 1622 in Amsterdam by Willem Janszoon Blaeu. It was based upon the Tychonic geo–heliocentric system of the world. But in contrast to Brahe, Longomontanus, like **Nicholas Bär** (Raimarus Ursus) before him, incorporated daily rotation of the Earth on its axis to explain the rotation of the fixed stars. The book represented the real inheritance of Brahe – in the first half of the 17th century the Tychonic system, next to that of **Nicolaus Copernicus**, was one of the two main respected systems of the world. As the only Tychonic-based textbook, *Astronomia Danica* reached a wide audience, with two further editions (1640 and 1663) being published. The work was a complete presentation of astronomy including trigonometry (with many calculation examples), celestial circles, the obliquity of the ecliptic, terrestrial climate zones, rising and setting of objects, and a complete catalog of the Ptolemaic stars. It covered the movements of the planets according to the Tychonic, Ptolemaic, and Copernican theories as well as the production and handling of astronomic instruments, such as armillary spheres, armillae, the torquetum, the quadrant, the sextant, and the Jacob's staff – with reference to the printed instruction manuals by Brahe. An appendix is dedicated to the comets and their nature according to Rothmann, Brahe, and Kepler, with details on the novae and comets of 1572, 1577, 1607, and 1618.

Jürgen Hamel

Alternate name

Longomontanus

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Severus Sebokht [Sebokt, Sebukht, Seboht]

Born **Nisibis, (Syria), *circa* 575**
Died **Kennesrin (also called Qinnesrin or Qenneshrê), (Syria), 666/667**

Severus Sebokht was one of the leading figures of ecclesiastical, philosophical, and scientific culture of late antique Syria, although little definitive information is known about his life. Born in Persian territory at Nisibis, he left his teaching post in its famous school in 612 after a doctrinal dispute among the Nestorians. Later consecrated a bishop, he pursued a career in the Syrian Monophysite church within Byzantine jurisdiction, residing as a monk at the monastery at Kennesrin on the west bank of the Euphrates, one of the chief seats of Greek learning in western Syria. He continued to write until at least 665.

Like many of his contemporaries, Severus was bicultural, partaking of the Byzantine Greek influence on western Syrian intellectual circles while fully immersed in his own Syrian cultural milieu. He does, however, criticize the contemporary Greek tendency to assume intellectual superiority and asserts his own capabilities as a native Syrian, raising a strong polemical voice against the cultural hegemony of the Greek-speaking world over that of provincials. A leading figure in the teaching and commentary tradition of Aristotelian philosophy, especially in logic and syllogisms, Severus produced a *Discourse on Syllogisms in Prior Analytics* (638) and wrote commentaries on other philosophical texts. He translated Paul the Persian's commentary on **Aristotle**'s *De interpretatione* into Syriac. Severus also played an important role in the transmission of Indian intellectual concepts into Syria and ultimately into the Islamic world. In one famous passage, he praises the Hindu decimal concept and mentions for the first time in the Greek east the nine numerical symbols used in India.

It was in astronomical matters, however, that Severus was preeminent. Syrian astronomy was predominantly Ptolemaic, and Severus himself stands as an important figure in passing on Greek astronomical knowledge to Syrian scholars and thence to Islamic civilization. He was familiar with **Ptolemy**'s *Handy Tables*, and there is some indication that he translated the *Almagest* into Syriac; in any case, he most certainly taught it in the school of Nisibis and then later in western Syria. Similarly, Severus was an important link in the transmission of the Greek tradition of the astrolabe to the east. In several passages in his astronomical works, he positions himself firmly on the side of scientific methodology and opposes speculative astrology.

Severus made two major contributions to astronomy. The first, a *Treatise on the Astrolabe,* is based on a lost work by **Theon of Alexandria**, the contents of which Severus preserved in his own work. Written in 660, it is in two parts. The first is a general description, including information about the following basic elements of the instrument – the disks, the spider, the diopter, the zones, and related aspects of the physical and mechanical parts. Instructions on its actual use comprise the second part of the work, divided into 25 chapters, of which two (12, 20) are missing. These chapters cover all the applications of the instrument – determining the hour of the day and night (1–3), finding the longitude of the Sun, Moon, and planets and the latitude of the Moon (4–6), checking the instrument (7–8), ascertaining the rising and setting times of various signs (9–10, 25) and the length of daylight during the course of the year (11), locating the geographical longitude and latitude of cities and establishing the differences of local noons (13–15), fixing the ascensions on the right sphere (16), finding latitudes of the observer and of each climate (17–18), estimating the longitude and latitude of stars and their first and last visibility (19, 21), observing the ecliptic and the declination of the Sun (22–23), and recognizing the five zones on the celestial and terrestrial spheres (24).

Severus's other astronomical work (generally entitled *Treatise on the Constellations*) was written in 660, subsequent to that on the astrolabe. Eighteen original chapters are extant. The work begins with five chapters forming a scientific critique of astrological and poetic claims about the origins and significance of the constellations. In them, Severus shows that the figures of the constellations are not arranged in the heavens through natural means but rather are a result of human imagination. Importantly, Chapter 4 features extracts from the *Phaenomena* of **Aratus** concerning many of the constellations. The remaining 13 chapters (6–18) are devoted to a scientific analysis of the heavens and the Earth. Here Severus enumerates the 46 constellations and their noteworthy stars and explains their various motions and their rising and settings. He also discusses the celestial geography of the Milky Way and the ten "circles" of the heavens, including the tropics, the equator, the meridian, the horizon, and the ecliptic. Three chapters (14–16) examine extensively the seven climatic zones, their location and extent, their relationship to the Sun, and the length of the days and nights in each, the latter in accordance with Ptolemy's *Handy Tables.* In the final two chapters, Severus treats the extent of the Earth and the sky and considers the populated and uninhabited regions of the Earth. In 665, Severus appended to this work nine additional chapters, designed to answer a variety of astronomical, cosmological, and mathematical questions posed by Basil of Cyprus, a visiting cleric. Included are treatments of the conjunctions of planets and of various points about climatic zones, the astrolabe, the determination of the date of Easter in April 665, and the date of the birth of Christ. In other passages extant in the manuscripts, Severus also writes on the phases of the Moon and on eclipses, in one case explaining lunar eclipses scientifically to dispel the popular idea that a dragon (*Ataliâ*) was responsible for such events.

John M. McMahon

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Seyfert, Carl Keenan

Born **Cleveland, Ohio, USA, 11 February 1911**
Died **Nashville, Tennessee, USA, 13 June 1960**

American observational astronomer Carl Seyfert is remembered in the name of the small group of galaxies, Seyfert's sextet, and, more particularly, in Seyfert galaxies, a class of spirals distinguished by bright, wide emission lines coming from gas near their centers and now believed to have nuclear black holes of millions to hundreds of millions of solar masses.

The son of a pharmacist, Seyfert was educated in the Cleveland schools, and at Harvard University, starting in 1929 in medicine, but turning to astronomy under the inspiration of **Bart Bok**. He received a BS (1933), an MA (1933), and a Ph.D. (1936), for work on colors and magnitudes of galaxies. His dissertation work was guided by **Harlow Shapley**. Seyfert married Muriel E. Mussells in 1935; their children are a daughter Gail Carol and a son Carl Keenan Seyfert, Jr., a well-known geophysicist and textbook author.

In 1936, Seyfert was appointed to the staff of the new McDonald Observatory (initially as part of the Yerkes Observatory staff), where he worked on spectra and light curves of hot stars and variable stars, including a project with **Daniel Popper** on faint B-type stars. Seyfert also worked on emission nebulae and clusters of stars in other galaxies. During his service at McDonald Observatory, Seyfert rode his horse, *Silver*, in a local cattle roundup each year.

Seyfert held a National Research Council Fellowship at Mount Wilson Observatory for the period 1940–1942, where he recognized the first half dozen examples of what are now called Seyfert galaxies, characterized by emission lines emitted by gas that is moving at very high speed at the center of the Galaxy. The first of these galaxies was actually discovered and published more than 30 years before Seyfert's key 1943 paper by **Edward Fath** but was not recognized for what it was. The best known of the original Seyfert galaxies is probably M77 (NGC 1068), and they are now regarded as a subtype (with spiral hosts) of the more general class of galaxies with active nuclei [AGNs].

In 1942, Seyfert returned to Cleveland to teach navigation to the armed forces at Case Institute, and do some war-related work in optics. He also used the facilities of nearby Warner and Swasey Observatory in collaborations with S. W. McCuskey and J. J. Nassau, on stars and planetary nebulae in the Milky Way and in the Andromeda Galaxy, M31. Seyfert and Nassau obtained the first good color photographs of nebulae and of stellar spectra during this period, using a new Schmidt telescope as an objective prism spectrograph.

In 1946, Seyfert joined the faculty of Vanderbilt University in Nashville, Tennessee. At that time, the university had only the small Barnard Observatory, equipped with a 6-in. refractor (which had once been used by **Edward Barnard**) and a modest teaching program in astronomy. With considerable vigor, Seyfert started a new series of courses, and set out to build a new observatory. Within a few years, while busy with full-time duties in teaching and research, Seyfert managed to get public support from the Nashville community. During the work-intensive planning and construction of the new observatory, he still found time to give astronomy lectures outside the university, and even appeared on television as a daily weather forecaster.

The new Arthur J. Dyer Observatory, named after one of Seyfert's strongest supporters and equipped with a 24-in. reflecting telescope, was finally completed in December 1953. Carl Seyfert became director of Dyer Observatory, a post he held for the rest of his life. Research at the new observatory included stellar and galactic astronomy, as well as new instrumental techniques. During the time at Vanderbilt, Seyfert's research included first the photometric investigation of photographic plates from Barnard Observatory and Shapley's Harvard plates, as well as studies performed with the privately owned 12-in. J. H. DeWitt telescope. In 1951, Seyfert observed and described a group of galaxies around NGC 6027, now known as Seyfert's sextet.

He was involved in instrumental innovations including the use of photomultiplier tubes and television techniques in astronomy, and electronically controlled telescope drives. Scientific results were obtained on variable stars, emission B stars in stellar associations, and the structure of the Milky Way. Seyfert was a member of several professional societies, including the American Astronomical Society, where he served on the council from 1955 to 1958, and the Royal Astronomical Society. He also served in the Associated Universities Incorporated, as a member of the board of directors of the Association of Universities for Research in Astronomy, and on the astronomy Advisory Panel of the National Science Foundation.

Carl Seyfert died in an automobile accident. He was honored by the astronomical community by the naming of Moon crater Seyfert in 1970. The 24-in. telescope at Dyer Observatory, for which he had worked so hard, now carries his name, the Seyfert telescope.

Hartmut Frommert

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Shain [Shayn, Shajn], Grigory Abramovich

Born **Odessa, (Ukraine), 13 April 1892**
Died **Moscow, (Russia), 27 August 1956**

Astrophysicist and observatory director Grigory Shain helped to rebuild the infrastructure of Soviet astronomy in the wake of the Bolshevik Revolution and provided early evidence for nonsolar abundances in carbon stars and for a galactic magnetic field.

Shain was born into a poor joiner's family; much of his broad erudition was due to his perseverance and determination to educate himself. In 1912, he enrolled in the Faculty of Physics and Mathematics at Yurev (Dorpat) University, but his education was not completed until 1919 at Perm (following his service in World War I). Shain earned a magister's degree from the provincial Tomsk University (1920) and, in the following year, joined the staff of Pulkovo Observatory. He married astronomer Pelageya Fyodorovna Sannikova.

In 1925, Shain and his wife were dispatched to Pulkovo's astrophysics branch at Simeiz, Crimea. He remained there for the rest of his life. It is likely that Shain's peripheral location with respect to the main scientific centers of the country not only saved his life during the terrible Pulkovo purges of the 1930s, but also permitted him to maintain his high moral standards. In 1939, he was elected an academician of the Soviet Academy of Sciences, a very high rank for an astronomer, especially during the Stalinist era. On many occasions, Shain risked his own safety by signing his name to the defense of innocent victims of the regime, and he exerted great efforts to aid the families of imprisoned astronomers. In 1946/1947, he was the leader of a party of ten Soviet astronomers who studied in the United States during the 6 months prior to the beginning of the Cold War.

At the Simeiz Observatory, Shain was given charge of its 1-m reflector, constructed in the United Kingdom after World War I. He began his research in celestial mechanics, but then turned his attention to the evolution of binary stars, correctly deducing that the more massive star of a pair evolved more rapidly than its less-massive companion. In collaboration with Yerkes Observatory director **Otto Struve**, Shain pioneered studies of the rapid rotations of hot stars from measurements of their spectral line broadening.

Shain's principal accomplishments were in the fields of stellar spectrophotometry and the physics of gaseous nebulae. He offered new interpretations regarding the atmospheres of long-period variable stars, and gathered evidence of significantly higher isotopic abundances of ^{13}C to ^{12}C (compared to the solar abundance) in some other stars. This research netted Shain a Stalin Prize of the first class (1950), the supreme scientific award of that time. Using two especially fast optical systems he had developed, Shain and colleague Vera F. Gaze discovered roughly 150 new galactic emission nebulae, by recording their light in the red H-α emission. Much of this work was summarized in Shain's 1952 *Atlas diffuznykh gazovykh tumannostey* (Atlas of diffuse gas nebulae). The filamentary shapes of many of the nebulae were oriented parallel to the galactic Equator, which led Shain to postulate the existence of powerful galactic magnetic fields.

Following destruction of the original Simeiz Observatory during World War II, Shain spearheaded establishment of the newer and larger Crimean Astrophysical Observatory in 1945. He directed that institution until 1952, when he voluntarily stepped down for health reasons. Throughout his life, Shain was surrounded by a handful of disciples, such as Solomon Pikelner, and other prominent scientists, including **Iosif Shklovsky**. Additional astronomers of his circle included his wife and son-in-law, **Victor Ambartsumian**.

Shain had significant influence on contemporary Soviet and world astrophysics. As Shklovsky has written, Shain was truly "a good astronomer and a remarkable man." The Crimean Astrophysical Observatory's largest (2.6-m) telescope, along with a crater on the Moon's farside, are named for him. Shain is buried on the observatory grounds in Ukraine.

Alexander A. Gurshtein

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Shakerley, Jeremy

Born **Halifax, (West Yorkshire), England, November 1626**
Died **possibly (India), *circa* 1655**

Jeremy Shakerley was an English astronomical writer who first championed **Jeremiah Horrocks**'s views on the motions of the Moon and Venus and who observed the 1651 transit of Mercury. Shakerley spent his youth in Yorkshire and by January 1648 was living in Pendle Forest, Lancashire. Around this time, he became acquainted with the works of **Johannes Kepler** and **Ismaël Boulliau**. Shakerley subsequently expanded his knowledge of astronomy with the assistance of the astrologer William Lilly, with whom he began a 3-year correspondence in 1648, and of Christopher Towneley, in whose household at Carre Hall, Burnley, Lancashire, he began living in 1649. Towneley had acquired the manuscripts of the Liverpool astronomer Horrocks after the latter's death in 1641, and Shakerley was the first person to appreciate the significance of Horrocks's works, especially those on the theory of the Moon's motion. Shakerley made references to Horrocks's lunar theory in *The Anatomy of Urania Practica* (1649), a critique of the work of the almanac maker **Vincent Wing**.

Shakerley also cited the work of Horrocks, who had predicted and observed the transit of Venus across the Sun in 1639, in making his own prediction (in his 1651 almanac *Synopsis Compendia*), that a transit of Mercury would occur on 24 October 1651. Having lost the support of Lilly in 1650 after attacking Wing, Shakerley soon thereafter immigrated to India, probably as an employee of the East India Company. The move enabled him to observe, from Surat, the 1651 transit. His observation of this transit, which was not visible in England, marked only the second occasion when observations of the phenomenon were recorded. (The French scientist **Pierre Gassendi** and two others had observed the Mercury transit that occurred on 7 November 1631.)

Virtually nothing is known about Shakerley's life after his *Tabulae Brittannicae* was published in London in 1653.

Craig B. Waff

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Shams al-Dīn al-Bukhārī

Flourished **Middle to late 13th century**

Shams al-Dīn al-Bukhārī is cited in various Greek versions of Arabic and Persian astronomical handbooks (*zīj*es), versions that were made in the last decade of the 13th century in Marāgha and Tabrīz. These *zīj*es include *al-Zīj al-Sanjarī*, composed in Arabic in the mid-12th century by **ʿAbd al-Raḥmān al-Khāzinī** and dedicated to the Saljūq Sultan Sanjar (reigned: 1118–1157); *al-Zīj al-ʿAlāʾī*, composed in Arabic by ʿAbd al-Karīm al-Shirwānī al-Fahhād (mid-12th century), but no longer extant in Arabic; and, *al-Zīj-I Īlkhānī*, composed *circa* 1270 in Persian by **Naṣīr al-Dīn al-Ṭūsī**. The Persian text survives in many copies, and there is also an Arabic version. The Greek versions of all three are found in the following manuscripts: Florence Laur. gr. 28/17, Vat. gr. 211, and Vat. gr. 1058. The Greek version of the *Īlkhānī zīj* is much more widespread, being found in manuscripts in many collections. The Arabic version of the *Sanjarī* is found in manuscripts Vat. ar. 761, Br. Lib. Or. 6669, and Istanbul Hamidiye MS 859; one is in private possession.

A tract on the astrolabe is also attributed to Shams al-Dīn al-Bukhārī as well as a "Short syntaxis"; both are in Greek. There is nothing known of him in Persian or Arabic sources, nor is there any known reference to him outside the Greek work just mentioned. According to these sources, his *floruit* may be firmly placed at the end of the 13th century, and D. Pingree (1985) has argued for his date of birth as 11 June 1254.

These translations were made, no doubt, within the community centered at the famous observatory of Marāgha, which was under the direction of Ṭūsī and under the patronage of the Īlkhānid rulers. It is clear that Shams al-Dīn al-Bukhārī was instrumental in enabling the Byzantine scholar **Gregory Chioniades** both to obtain these translations of the tables and to learn how to use them. Shams al-Dīn's oral instruction (ἀπὸ φωνῆς τοίνυν τοῦ Σὰμψ Πουχαρὴς ἀνδρὸς τὸ γένος Πέρσου) is acknowledged in the prefaces to the "Persian syntaxis" of Chioniades, *circa* 1295, and in the later "Persian syntaxis" of George Chrysococces, *circa* 1347, where we are told that the Persians were reluctant to allow a written translation of the Persian canons of the tables to be passed into Greek hands. One notes that the term "Persian syntaxis" is used somewhat loosely in the Greek texts, so that, for Chioniades, it refers to the *Zīj al-ʿAlāʾī*, while for Chrysococces it means the *Zīj-i Īlkhānī*.

Apart from Chioniades's canons for *Zīj al-ʿAlāʾī*, one finds a further work of his in 22 chapters, in which all three *zīj*es are mentioned. In one of these, Chioniades relates how Shams al-Dīn al-Bukhārī calculated a lunar eclipse according to some tables he had devised on the basis of the *Zīj-i Īlkhānī*, using as an example the total lunar eclipse of 30 May 1295. These eclipse tables were presumably part of the "Short syntaxis" elsewhere attributed to him.

The last mention of Shams al-Dīn al-Bukhārī in the Byzantine sources is in the *Tribiblos*, a very prolix treatise written *circa* 1350 by Theodore Meliteniotes, covering both Ptolemaic and Persian material. This includes in its Book III a long recapitulation of the Persian material, including the Greek version of the *Zīj-i Īlkhānī*, as already given by Chrysococces. In the preface to the text, Meliteniotes mentions Σάμψ Μπουχαρὴ along with other Islamic authors (Vat. gr. MS 792, fol. 246).

Raymond Mercier

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Shane, Charles Donald

Born **Auburn, California, USA, 6 September 1895**
Died **Santa Cruz, California, USA, 19 March 1983**

American observational astronomer C. Donald Shane is eponymized in the 120-in. (3-m) Shane telescope at Lick Observatory, whose design and construction he oversaw. He made his most lasting impact on astronomy through the Shane–Wirtanen counts of galaxies, completed in 1954, which helped to establish the existence of structure in the Universe on the scale of superclusters.

Shane received an AB from the University of California [UC] (now UC Berkeley) in 1915 and took up a Lick Fellowship on Mount Hamilton the next year to work toward a Ph.D. in astronomy. After brief service (1917–1918) in World War I, he returned to complete his dissertation under **William Campbell** and **Joseph Moore** on the spectra of carbon stars.

Shortly before completing his degree, Shane married fellow graduate student Mary Lea Heger, who received her Ph.D. in astronomy in 1925, working on absorption features in stellar spectra caused by cool interstellar gas. They had two children, and she devoted many years to bringing order out of the chaos of the Lick Observatory archives, named the Mary Lea Shane Archives in 1982. She also died in 1983.

Donald Shane was appointed to an instructorship in mathematics at the University of California in 1920 (mathematics and astronomy 1922–1924) and to an assistant professorship in 1924. He moved up the ranks to full professor, and in 1945 officially became a full astronomer at Lick Observatory and then its director (1945–1958), retiring to an emeritus position in 1963. During World War II, Shane served first as assistant director of the Radiation Laboratory at Berkeley and later as personnel director at Los Alamos Laboratory.

Lick flowered under Shane's directorship, with the staff increasing from 50 to about 105, the building of the 120-in. telescope (which was the second largest in the world at the time of its commission), and the renewal of both facilities and research programs. He found time to serve as president of the Association of Universities for Research in Astronomy from 1958 to 1962, the critical years during which Kitt Peak National Observatory was being established and the Cerro Tololo Inter-American Observatory in Chile was being planned. Some of his own work concerned the detailed spectra of the Sun and of stars like o Ceti (Mira).

Shane's most important contribution came, however, when he and **Carl Wirtanen** decided to photograph the entire northern sky using the 20-in. Carnegie astrograph (a wide-field telescope generally used for astrometry) to take first-epoch plates for a major Northern Hemisphere proper-motion survey. This was eventually completed as the Lick Sky Atlas. But, in the meantime, Shane and Wirtanen decided to count all the galaxies they could see on the plates, recording what they saw in a new way. Instead of representing each galaxy by a position on the sky, they divided the sky into small boxes and recorded the number of galaxies in each box. The 1954 analysis of these counts by statisticians J. Neyman, Elizabeth Scott, and Shane himself persuaded most of the astronomical community, first, that virtually all galaxies are parts of groups and clusters and, second, that there is a good deal of higher-order clustering of these into superclusters. Nearly three decades later, these counts were the best available data of their sort when cosmologist P. James E. Peebles used them to establish quantitative measures of the length scale and amplitude of that clustering behavior. The Shane–Wirtanen counts have only recently been rendered obsolete by very large surveys that include measured redshifts.

Shane was a member of the United States National Academy of Sciences (1961) and a foreign associate of the Royal Astronomical Society (London) and of the Royal Astronomical Society of New Zealand, for whose members he had provided guidance in starting an extension of the Lick Atlas to the Southern Celestial Hemisphere. The Shanes were survived by two sons.

Virginia Trimble

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Shapley, Harlow

Born **near Nashville, Missouri, USA, 2 November 1885**
Died **Boulder, Colorado, USA, 20 October 1972**

American observational astronomer Harlow Shapley obtained the data that showed incontrovertibly that the Solar System is not near the center of the Milky Way Galaxy, as virtually all astronomers had thought since the time of **William Herschel**. His name is remembered in the Shapley concentration of galaxies (a very extensive supercluster) and in the Shapley–Ames catalog of nearby galaxies. Shapley was the son of Willis and Sarah (*née* Stowell) Shapley. After completing elementary school and a short business course, and before graduating from high school in 1907 (first in

a class of three from Carthage Collegiate Institution in Carthage, Missouri), he spent several years as a newspaper reporter – first in Chanute, Kansas, and then in Joplin, Missouri. Shapley then entered the University of Missouri. Finding that the new School of Journalism, which had been his goal, was not yet open, he quickly gravitated toward astronomy, under the influence of **Frederick Seares**, with whom he worked on light curves of variable stars, mostly eclipsing binaries. Shapley received a BA in 1910 and an AM in 1911, going on that year to Princeton University with a Thaw Fellowship.

Working officially with **Henry Norris Russell** and also mentored by **Raymond Dugan**, who was more observationally inclined, Shapley received a Ph.D. in 1913 for the analysis of the light curves of a large number of eclipsing binaries. He was able to measure sufficiently accurate masses and radii for the component stars to conclude that the range of stellar densities is more than 1,000, but that density is not correlated with surface temperature in the way that Russell (with his giant-and-dwarf theory of stellar evolution) was expecting. Seares had by then moved to Mount Wilson Observatory and arranged for Shapley to meet its director, **George Hale**. After a year in Europe, during which he met many astronomers, Shapley accepted a position at Mount Wilson Observatory.

In 1914, Shapley married fellow Missourian Martha Betz. Trained as a mathematician, **Martha Shapley** quickly acquired skill in analyzing variable-star light curves to extract binary properties, and published a number of papers alone and with Shapley between 1915 and 1929. Of their five children, Mildred Shapley Matthews became a planetary astronomer, Lloyd a mathematician, Alan a geophysicist, and the others (and some of the grandchildren) scientists, science administrators, and teachers of other sorts.

Before moving west, Shapley had visited Harvard astronomer **Solon Bailey** who urged him to use the 60-in. telescope on Mount Wilson (then the largest) to observe variable stars in globular clusters. This he did as soon as the opportunity presented itself. Contemporary astronomers were generally of the opinion that the Cepheid variables (for which a correlation between absolute luminosity and length of period had been discovered earlier by **Henrietta Leavitt** for stars in the Small Magellanic Cloud) were eclipsing binary pairs. Shapley carried out an analysis demonstrating that this could not possibly be true, for the separation of the stars would have to be smaller than their sizes, putting one star inside the other. In 1914, he advanced an alternative idea that the stars were pulsating radially in size, with corresponding changes in surface temperature and brightness. This proved to be correct. Shapley also tacked on to the faint end of the period–luminosity relation a class of more rapid variables, then called cluster-type (though they also occur outside globular star clusters) and now called RR Lyrae variables. This eventually caused problems.

The pulsation mechanism, however, suggested that the Cepheids could be reliable distance indicators, if only one could calibrate them with a few stars whose real luminosities (or distances) were known in some other way. **Ejnar Hertzsprung** had attempted such a calibration, using the method of statistical parallaxes invented by **JacobusKapteyn**, and Shapley adapted and improved this. Shapley's calibration was an important advance, but three effects combined to introduce errors into his period–luminosity relation. These were (1) neglect of galactic rotation (not discovered until a decade later by **Bertil Lindblad**), (2) his own work, which seemed to show that there was no general absorption of starlight in interstellar space (proven wrong in 1930 by **Robert Trumpler**), and (3) slightly bad luck in the statistics of very small motions on the sky for a small number of stars. He was, moreover, mistaken in thinking that the nearby Cepheids (on which the calibration was done), and those in globular clusters, were physically similar. In fact, they differ in mass by a factor of 5–10 and in brightness by factors of 2–10, so that Shapley put his globular clusters too far away when he started using Cepheids as rulers.

Shapley had come to Mount Wilson as a believer in the "island universe," or many galaxies hypothesis, under which the Milky Way and the spiral nebulae were similar kinds of systems. But the map Shapley gradually drew of the locations of the globular clusters eventually persuaded him, first, that the Solar System was very far from the center. (His center was actually within the grouping of clusters toward Sagittarius, an idea advanced earlier by Swedish astronomer **Karl Bohlin.**) Second, Shapley was persuaded that the Milky Way extended to at least 50,000 parsecs from that center, making the idea of other galaxies of comparable size most unlikely. He was further misled by his own discoveries of some novae in the Andromeda Nebula that he decided were not as bright as galactic novae (leaving only the 1885 event, now known to have been supernova 1885A, as a distance indicator) and by apparent measurements of the rotation in the plane of the sky of several spiral nebulae, carried out on Mount Wilson plates by **Adriaan van Maanen**. **Knut Lundmark** later showed that Van Maanen's measures were completely erroneous, but Shapley, who regarded van Maanen as a friend, was not convinced.

Against this background, Shapley and **Heber Curtis** engaged in a discussion of "the distance scale of the universe" before the National Academy of Sciences in Washington, in April 1920. Shapley advocated a very large Milky Way with the Sun far from the center and the spiral nebulae and globular clusters as members of this one, universal system. Curtis advocated a much smaller Milky Way, with the Solar System close to the center, and the spirals as independent similar systems of stars. The event is frequently called the Great Debate or the Curtis–Shapley debate, though it was not actually organized as a debate. In retrospect, Curtis was right about other galaxies existing (shown by **Edwin Hubble** a few years later), and Shapley was right about the noncentral position of the Solar System, which was quickly adopted by the entire community, relegating the smaller Kapteyn universe to the status of a relatively local feature in the galactic disk. The modern distance scale within the Milky Way is about half way between those of Curtis and Shapley.

The death of **Edward Pickering** in 1919 had left Harvard Observatory directorless. Those charged with naming Pickering's successor attended the debate to evaluate Shapley for the position. It was offered to him, first on a visiting basis, and then permanently in 1921. At Harvard, Shapley carried out investigations in many areas, including studies of the Magellanic Clouds, star clusters, and variable stars. The Shapley–Ames catalog of galaxies, published with Adelaide Ames in 1932, was an important survey of galaxies brighter than the 13th magnitude. That and follow-up surveys, extending to fainter magnitudes, provided early indications that galaxy clustering might be important on large scales. Indeed, Shapley eventually came to the opinion that most galaxies are clustered (the modern view) and himself recognized several of the large clusters and concentrations.

Shapley's view of the clustering of galaxies was another source of disagreement with Hubble, who saw most galaxies as part of a general field. The antipathy felt by both astronomers may have dated from their overlap at Mount Wilson Observatory. Shapley remained a civilian during World War I, arriving in 1914, while Hubble volunteered for army service in Europe, arriving at Mount Wilson in 1919 to find that Shapley had initiated some studies that he himself had intended to pursue. That antipathy gradually emerged as full-blown antagonism as their careers diverged, with Hubble garnering fame through the scientific fruits of his work with the most powerful telescope in the world while Shapley administered at the Harvard College Observatory.

In 1938, Shapley reported the discovery of the Fornax and Sculptor systems, the first of the dwarf spheroidal galaxies that are satellites of the Milky Way. He completed publication of the Henry Draper Catalogue of Spectral Classifications, a project begun under Pickering, and organized the Henry Draper Extension. Together, these surveys provided spectral classifications for 359,000 stars. Shapley also continued Pickering's support for the American Association of Variable Star Observers, whose members were mainly amateur astronomers. His support for amateurs was evident in other ways, including his founding of the Bond Astronomy Club and support for the Amateur Telescope Makers of Boston.

Harvard Observatory, despite its location next to the oldest university in the country, had been a purely research institution. Shapley built it into one of the country's strongest education programs in astronomy. Many of his early students (including **Cecilia Payne-Gaposchkin**, **Helen Sawyer-Hogg**, and **Dorrit Hoffleit**) and his early appointments to the Harvard College Observatory staff (**Henrietta Swope**, **Bart Bok**, **Donald Menzel**, and **Fred Whipple**) also appear in these pages. He moved the Harvard Southern Station from Arequipa, Peru, to Bloemfontein, South Africa, and hosted at Harvard the headquarters of the American Association of Variable Star Observers and the editorial offices of *Sky & Telescope*, the most important popular astronomy magazine in the United States.

Shapley retired from the directorship in 1952 (to be succeeded by Menzel) and from his Harvard professorship in 1956, although he maintained an active interest in astronomical innovation until very late in life, visiting, for instance, the first observatory designed to look for gravitational radiation in 1969.

A brilliant public speaker, Shapley enjoyed popularizing science, especially astronomy. He arranged an extended series of radio talks on astronomy when that medium was still comparatively young. Later, with Bok, he initiated the Harvard Books on Astronomy, popular volumes that filled a growing demand for informative books on what was happening in astronomical research. These were written by some of the leading astronomers of the time. Some books in the Harvard Books series went through four editions before the series was cancelled.

Shapley had always been an outward-looking, publicly oriented scientist, serving, for instance, as one of the first presidents of the Commission on Galaxies of the International Astronomical Union in the 1920s. In the late 1930s, he became increasingly concerned about what was happening to German, and later European, scientists and spent a great deal of time helping to resettle refugees before, during, and after the World War II. Shapley was actively involved in the processes that led to the establishment of the National Science Foundation, Science Service Inc. (the publishers of *Science News* and coordinators of the science talent search, of which he was president), and UNESCO, where he was a strong advocate for the inclusion of the "S" (science) component. He served terms as president of the American Astronomical Society, the American Association for the Advancement of Science, and Sigma Xi (the scientific research society), as well as gave very large numbers of public lectures and served as a board member of the Belgian–American Education Foundation, the Worcester Foundation for Experimental Biology, and many others. Shapley was a strong opponent of "fringe science," helping to coordinate opposition to the ideas of Immanuel Velikovksy and the flying saucerites. At some point, this pattern was perceived as threatening to United States security, and he was called before the House Un-American Activities Committee for alleged (and completely untrue) Communist connections and sympathies.

His own scientific colleagues recognized and rewarded Shapley's work in many ways. He held 16 honorary degrees (ten from within the USA and six others), was elected to the United States National Academy of Sciences and to science academies in nine other countries, and received medals and awards from the American Astronomical Society, the Royal Astronomy Society, the French Astronomical Society, and others.

Horace A. Smith and *Virginia Trimble*

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Shapley, Martha

Born **Kansas City, Missouri, USA, 3 August 1890**
Died **Tucson, Arizona, USA, 24 January 1981**

Besides doing calculations for her husband **Harlow Shapley**, American Martha Betz Shapley was an authority on eclipsing binary stars in her own right.

Alternate name

Betz, Martha

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Sharaf al-Dīn al-Ṭūsī

Born **Ṭūs, (Iran), *circa* 1135**
Died **(Iran), 1213**

Although Sharaf al-Dīn al-Ṭūsī is known especially for his mathematics (in particular his novel work on the solutions of cubic equations), he was also the inventor of the linear astrolabe, a tool that derives from the planispheric astrolabe but is more easily constructed. From his name we may infer that Sharaf al-Dīn was born in the region of Ṭūs, in northeastern Iran. He spent a major part of his early career as a teacher of the sciences, including astronomy and astrology, in Damascus and Aleppo; he also taught in Mosul. Among his students was Kamāl al-Dīn ibn Yūnus, who would eventually teach Sharaf's namesake, the great **Naṣīr al-Dīn al-Ṭūsī**.

Sharaf al-Dīn al-Ṭūsī devoted several treatises to the linear astrolabe, sometimes called the staff of al-Ṭūsī. Its principle is simple – many of the important circles on the planispheric astrolabe, especially the almucantars (altitude circles) and the circles of declination, are centered on the meridian line. The main rod of the linear astrolabe is equivalent to the meridian line and contains markings to indicate the centers of these circles and their intersections with the meridian. The ecliptic (which appears on the movable rete of a standard astrolabe) is represented by the intersections of the beginnings of the zodiacal signs with the meridian when the rete is rotated. Many typical operations on a traditional astrolabe require the locations of points of intersection of these various circles. By attaching ropes to the appropriate points on the staff to act as radii, the circles and their intersections can be reconstructed and the astronomical problem solved. A scale giving chord lengths in the meridian circle extended the linear astrolabe's range of applications. Attached to a plumb line, it was also used to take observations of solar altitude. Additional markings allowed the determination of the *qibla* (the direction of Mecca) and solutions of astrological problems.

The simplicity of the linear astrolabe made it easy to construct, but its less than artful appearance rendered it unattractive to collectors. It was neither as durable nor as accurate as a planispheric astrolabe, and its operations were less intuitive. None have survived.

Glen van Brummelen

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Sharonov, Vsevolod Vasilievich

Born **Saint Petersburg, Russia, 25 February/10 March 1901**
Died **Leningrad (Saint Petersburg, Russia), 27 November 1964**

Soviet astronomer Vsevolod Sharonov was one of the leading proponents of lunar and planetary exploration before the advent of robotic spacecraft. Sharonov enrolled in the Faculty of Physics and Mathematics at Petrograd University (renamed Leningrad State University) in 1918; he did not complete his degree until 1926, having served in the Red Army (1919–1924). Most of Sharonov's professional career was spent at Leningrad State University.

In 1929, Sharonov defended his dissertation on the theory and application of the wedge photometer. He worked on problems of aerophotometry at the Institute of Air Surveys (1930–1936) and organized a photometric laboratory for the task. From 1941 to 1944, he directed the university's astrophysics laboratory, which was evacuated to Yelabuga, Tatarstan, during World War II. Sharonov was appointed professor (1944) and later director (1951) of the university's astronomical observatory. Portions of his observational work were conducted at the Pulkovo, Simeiz, and Tashkent observatories.

Sharonov worked out new methods of absolute photometry and colorimetry, which have been applied to studies of the solar corona. (He observed seven total solar eclipses between 1936 and 1963.) His photometric studies of the lunar surface compared its composition to that of terrestrial volcanic rocks, with a view toward understanding whether layers of microscopic dust covered the Moon's surface. Sharonov modeled the atmosphere of Mars and argued for the presence of the mineral limonite on the Martian surface.

In the course of his research, Sharonov devised a number of new instruments for astronomical and geophysical observations, which included a haze gauge, a diaphanometer (an instrument that measures transparency of the atmosphere), and a visual colorimeter. He was married to astronomer N. N. Sytinskaya. A crater on the Moon's surface has been named for Sharonov.

Yuri Balashov

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Sharp, Abraham

Born **Bradford, (West Yorkshire), England, 1 June 1653**
Died **Bradford, (West Yorkshire), England, 15 August 1742**

Abraham Sharp was a highly skilled instrument maker contemporary with **Isaac Newton** and **John Flamsteed**, and several such eminent people seem to have relied on the instruments that he constructed for precise measurements of the positions of the stars. Sharp was born and died at Little Horton Hall in Bradford. (His birth year was given as 1651 by the *Dictionary of National Biography*, but W. Cudworth argued that 1653 is the correct date). Like so much of Bradford's heritage, his birthplace has regrettably been demolished – the site is now occupied by a car park for Saint Luke's Hospital and the Unity Building of the University of Bradford.

Sharp attended Bradford Grammar School and worked for a period in the textile trade in York and Manchester, before moving to Liverpool where he taught and studied mathematics. Here, he met the eminent astronomer, Flamsteed, who used his influence to get employment for Sharp at the Royal Naval dockyard in Chatham. From about 1684, Sharp was associated with Flamsteed at the Greenwich Observatory, and in 1688 he was employed to make a "mural arc," a large astronomical elevation-measuring device. Sharp developed a considerable reputation for the accuracy of his graduations on such devices, and this mural arc, which had a graduated scale with a radius of 2 m, was used by Flamsteed to make the observations from which the entries in the "British Catalogue" were deduced.

Sharp left the observatory in 1690 in order to teach mathematics in London, but in 1691 he moved to another naval dockyard, Portsmouth. Unfortunately, there appears to have been a problem with his health, and he retired to his family home in Bradford in 1694. His health recovered, but he inherited the family estate on the death of his nephew, and Sharp decided to remain in Bradford, setting up a workshop for the construction of instruments. In these 49 years in Bradford, he made astronomical instruments and also undertook many extensive mathematical calculations, particularly for the generation of tables of astronomical events. Sharp also calculated π to 72 decimal places and logarithms to 61 decimal places. He appears to have obtained many contracts from Flamsteed, and several biographies are laden with quotations from Flamsteed's letters to Sharp, who seems to have been something of a sounding board for the former. A large proportion of the letters from Flamsteed are highly critical of Newton, but it is not clear whether Sharp shared these views. It may be noteworthy that there is a story that Newton visited Sharp at Little Horton Hall, and so it could be that the letters are primarily a reflection of Flamsteed's views. It is probably a fair assessment to say that Sharp made a major contribution to the refinement of astronomical measurement techniques, enabling Newton and others to test and refine their theories of planetary movements.

In the letters between Sharp and Flamsteed, there are several interesting references to striking observations of the aurora borealis from Bradford in the early 18th century. Sunspot and geomagnetic field conditions must have been very unusual indeed for this effect to have been seen so clearly so far south.

Although Sharp may appear to be "just" an instrument maker and mathematician, a measure of his significance in the astronomical community may be gained from the fact that there is a crater on the nearside of the Moon that is named for him.

Philip Edwards

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Shi Shen

Flourished **China, 4th century BCE**

Uranographer Shi Shen was a court astronomer during the late Waring States Period. He shares with Kan Te and Wu Xian credit for the earliest extant Chinese celestial chart. It shows 800 stars, comparable with the number in early Greek catalogs.

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Shibukawa, Harumi

Born **Kyoto, Japan, 1639**
Died **Edo (Tokyo), Japan, 1715**

Harumi Shibukawa inaugurated his country's first calendar reforms in many centuries and belonged to the first generation of Japanese scholars who assimilated knowledge of western astronomical ideas and practices. Shibukawa was born into the Yasui family; his father was a professional *go* (board game) player. As a child, he was called Rokuzo. After his father's death in 1652, Shibukawa took up *go* as a profession and adopted his father's first name, Santetsu. From early childhood, he had the reputation of being a prodigy and showed a remarkable understanding of astronomy and calendar study. Shibukawa received his education from many of the leading scholars of the day. These included Ansai Yamazaki, with whom he studied Confucianism and the *Shinto* doctrine, and both Jyunsho Matsuda and Gentei Okanoi, from whom he received training in calendrical methods.

Shibukawa spent most of his life in Edo (present Tokyo) but passed time in Kyoto when he was not playing *go*. He acquired a strong reputation, not only for his excellent skill at this game but also for numerous other subjects. In his writing, Shibukawa used the pen names of Harumi and Shunkai. He attracted many passionate and eager students along with wealthy patrons who invited him to lecture. Among the latter were Mitsukuni Tokugawa (*daimyo* of Mito Province, present Ibaragi and Tochigi prefectures) and Masayuki Hoshina of Aizu Province (now a part of Fukushima prefecture); these were two of the most influential political figures in Edo Japan (1603–1867). Hoshina later recommended Shibukawa to the *shogun* as the person most qualified to carry out calendar reforms.

In many ways, Shibukawa's attempts to gain recognition for his work show not only intelligence but also a great deal of courage and perseverance. At that time, calendrical practices lay in the hands of the bureaucratic Tsuchimikado family of Kyoto. Decisions about calendar reform seem to have been based far more on whether or not this family's political prestige would be maintained and enhanced rather than whether a calendar was accurate or not. Besides, few nobles would take a *go* player seriously. Shibukawa had to pay homage to the Tsuchimikado family while trying to develop his own calendrical methods, such often being in opposition to the outdated systems then in use. In the end, empiricism, coupled with a healthy dose of pragmatism, won the day. Shibukawa's calendar was accepted, and for the first time in 800 years, calendar reform became a reality.

In developing his own mathematical astronomy, Shibukawa insisted upon a strong positivistic base. This empirical orientation influenced generations of astronomers and calendrical scholars who followed. At the same time, he concluded that ancient writers of the Chinese classics must have had reasons for seeing aspects of the world in the way they did. Shibukawa felt that no one schema could explain everything; he wrote that astronomers should be versed in both portent astrology and calendrical science. The stimulus for his interest in calendar reformation came from discrepancies between his observations and ancient records. He felt such discrepancies could be explained by variations in the length of the solar year, a perceived phenomenon that was to influence later calendar scholars as well. Within Shibukawa's inclusive approach, he felt that irregular motions of the heavenly bodies were admissible; thus, it was unnecessary to be overly concerned with spatial relationships of the Sun, Moon, and planets – issues that were of major concern in contemporary Europe.

Shibukawa is best known for his reform of Japan's lunar calendar. By the late 17th century, the *Senmyo Reki*, a lunar calendar originating in the Chinese Tang dynasty, had been in use since 862 and was 2 days behind the solar year. Shibukawa became an outspoken proponent of calendar reform. The new calendar, officially put in place in 1685, was named the *Jyokyo Reki* and was the first calendar to be constructed by a Japanese citizen. It remained in use until 1755.

In formulating his own system, Shibukawa preserved the structure and theory behind the 13th-century *Shou-shih* calendrical treatise written by **Guo Shuoujing** of the Yuan dynasty in China. However, he incorporated into the *Jyokyo Reki* the difference in longitude between Japan and China. His calendar predicted apparent solar and planetary movement more accurately than did any produced by the official Yin-Yang board headed by Kyoto's Tsuchimikado family.

Precise astronomical observation was necessary for Shibukawa's work in calendar reform, and he enthusiastically used a number of instruments including the armillary sphere. With his penchant for observation, he compiled a number of star maps including the *Tensho Retsuji no Zu* (1670), *Tenmon Bunya no Zu* (1677), and *Tensho Seisho Zu* (1699), the last being published under his son's name, Hisatada.

Following his achievements, Shibukawa was officially appointed to the Tenmongata (Bureau of astronomy) in 1684. He moved his residence to Edo in 1686, and set up an astronomical observatory. In 1692, he was promoted to the *Samurai* class, and in 1702 once again changed his surname to Shibukawa, the original surname of the Yasui family and the name by which he is perhaps best known.

Shibukawa's tomb is located in the compound of Tokai Zen temple in Shinagawa, Tokyo.

Steven L. Renshaw and *Saori Ihara*

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Shīrāzī: Quṭb al-Dīn Maḥmūd ibn Masʿūd Muṣliḥ al-Shīrāzī

Born **Shīrāz, (Iran), October/November 1236**
Died **Tabrīz, (Iran), 1311**

Quṭb al-Dīn al-Shīrāzī was one of the most prominent theoretical astronomers of the 13th century. Born into a family of physicians, he studied with his father Ḍiyā' al-Dīn al-Kāzarūnī at the then new Muẓaffarī Hospital. When Shīrāzī was 14, his father died but even at that young age he was able to assume his father's position at the hospital. He continued his studies, at first with an uncle, also a physician, and later with two prominent teachers, Shams al-Dīn Kīshī and Sharaf al-Dīn Būshkānī. These studies included most prominently the "general principles" of **Ibn Sīnā**'s *Canon of Medicine* as well as Sufi mysticism, which had been another important part of his father's life. Uncharacteristic for someone of his talents and searching intellect, Shīrāzī remained in Shīrāz until the age of 24, most likely because of the turmoil in Iran brought on by the Mongol invasions.

But the Mongols also provided Shīrāzī with a unique opportunity, that of studying at the Marāgha Observatory with its director **Naṣīr al-Dīn al-Ṭūsī**. Though Shīrāzī was probably seeking to further his medical education, he soon turned to serious studies of philosophy and the mathematical sciences, especially astronomy, and would become Ṭūṣī's most prominent student. In Marāgha, he also studied with the philosopher Najm al-Dīn al-Kātibī and with the renowned astronomer **Mu'ayyad al-Dīn al-ʿUrḍī**. Even though based in Marāgha, Shīrāzī seems to have traveled a great deal for both teaching and learning. Sometime in his mid-30s, before the death of Ṭūsī in 1274, he may have become estranged from his teacher and left Marāgha. Accounts vary, but this may have had to do with the secondary role he was assigned at the observatory, or to not being named by Ṭūsī in the *Ilkhānī Zīj*, the handbook with tables that was produced at Marāgha. **Wābkanawī** states that Shīrāzī, though asked by Ṭūsī's son Aṣīl al-Dīn to help revise the *Zīj*, did so only in a perfunctory way because of his sense of having been slighted.

Sometime after leaving Marāgha, Shīrāzī traveled to Anatolia and studied for a time in Konya, perhaps meeting the famous Sufi poet Jalāl al-Dīn al-Rūmī. He was appointed chief judge in Malaṭya and Siwās and began to take an active role in political affairs, including acting as an emissary from the Mongol court to the Mamluks in 1282. Sometime around 1290, Shīrāzī retired to the city of Tabrīz in Azerbaijan where the Mongol court was located. But because of a falling out with the chief minister, he seems to have retired from government service and devoted himself to writing and teaching. It is of some interest that Shīrāzī dedicated his major philosophical encyclopedia, the *Durrat al-tāj*, to the ruler of an independent principality in western Gīlān in 1306; but later that year, the principality was brought under the control of the Mongols, and Shīrāzī was probably back in Tabrīz shortly thereafter.

Shīrāzī wrote three major works in theoretical astronomy – the *Nihāyat al-idrāk fī dirāyat al-aflāk* (The highest attainment in comprehending the orbs), dedicated to the Vizier Shams al-Dīn al-Juwaynī (who may have been responsible for his judgeship) and completed in November 1281; *al-Tuḥfa al-shāhiyya* (The imperial gift), dedicated to the Vizier Amīr Shāh ibn Tāj al-Dīn Muʿtazz ibn Ṭāhir in Siwās in July or August 1285; and *Faʿalta fa-lā talum* (You've done it so don't blame [me]), a supercommentary on the *Tadhkira fī ʿilm al-hay'a* by Ṭūsī. All have the characteristic four-part division of a *hay'a* (theoretical astronomy) work: an introduction, a section on the structure of the celestial region, a section on the structure of the terrestrial region, and a section on the sizes and distances of the celestial and terrestrial bodies. The *Nihāya* is the longest of the works, at some 300 or more pages in manuscript. It tends to present more of the work of Shīrāzī's predecessors than does the *Tuḥfa. Faʿalta* is a peculiar work in that Shīrāzī is ostensibly commenting on the commentary of the *Tadhkira* by a certain al-Ḥimādhī; in reality, it is a harshly worded attack on this author who, according to Shīrāzī, has plagiarized his *Tuḥfa.* This makes it an interesting work for the history of the notion of intellectual property. In addition to these straightforward astronomical works, there are also large sections related to astronomy in two of Shīrāzī's Persian works – the *Durrat al-tāj* and his *Ikhtiyārāt-i Muẓaffarī*, which was dedicated to the local ruler of a small emirate in Kastamonu. Large parts of the latter seem to be translations from the *Nihāya*.

Shīrāzī's works have not received the study they deserve, which is unfortunate since they promise to shed much light on the so called Marāgha school. Kennedy (1966) noted a number of innovative astronomical models in the *Nihāya* and the *Tuḥfa*, but Saliba showed that many of these models were due to Mu'ayyad al-Dīn al-ʿUrḍī. Shīrāzī should still be credited with new models for the Moon and Mercury (both in the *Tuḥfa*). He creatively uses what are now known as the ʿUrḍī lemma and the Ṭūsī couple to achieve combinations of uniform, circular motions (as required by ancient physics for motions in the heavens) that resolve the irregular motions resulting from **Ptolemy**'s equant for Mercury and from his choice of the center of the universe as the reference point of motion for the Moon's eccentric orb.

Shīrāzī' gives high praise to astronomy in his introduction to the *Nihāya* and echoes Ptolemy who, in his introduction to the *Almagest*, referred to physics and theology as guesswork as opposed to the true knowledge offered by the mathematical sciences. Indeed, it would seem that Shīrāzī somewhat disagreed with his mentor Ṭūsī on this point. This manifested itself in the question of the Earth's motion – Ṭūsī had held that the matter had to be left to the natural philosophers since there was no decisive observational or mathematical proof, whereas Shīrāzī, not wishing to leave such an important matter to "guesswork," insisted that there could be devised an observational test. This test took the form of two rocks of different weights thrown straight up in the air; Ṭūsī had said that in such a case a rotating Earth could carry the air and whatever was in it at the same speed, but Shīrāzī thought that objects of different weights would be carried with different speeds. Since we do not observe such an effect, the Earth must be at rest.

Shīrāzī's influence in astronomy was widespread. His words were copied and studied for several centuries. Often referred to simply as *ʿAllāma* (supremely learned), one finds citations to him by almost all later Islamic theoretical astronomers. In medicine, he was known for his extensive commentary on the first book of Ibn Sīnā's *Canon*, and he was to have a major influence on optics by recommending that his student Kamāl al-Dīn al-Fārisī undertake a study of **Ibn al-Haytham**'s *Kitāb al-manāẓir*.

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Shirwānī: Fatḥallāh ibn Abū Yazīd ibn ʿAbd al-ʿAzīz ibn Ibrāhīm al-Shābarānī al-Shirwānī al-Shamāhī

Born **Shirwān, Shamāh, (Azerbaijan), 1417**
Died **Shirwān, Shamāh, (Azerbaijan), February 1486**

The astronomer, mathematician, and teacher Fatḥallāh al-Shirwānī was part of the Samarqand school of mathematics and astronomy, which was composed of scholars who pursued the mathematical sciences including astronomy. Through his works many students were educated in the sciences, thus disseminating them in the Ottoman lands, especially in Anatolia.

Shirwānī received his primary education from his father and subsequently continued his education in Serakhs and Ṭūs. In Ṭūs, Shirwānī studied **al-Sayyid al-Sharīf al-Jurjānī**'s *Sharḥ al-Tadhkira fī ʿilm al-hay'a*, a commentary on **Naṣīr al-Dīn al-Ṭūsī**'s seminal work on astronomy, under the Shīʿī scholar al-Sayyid Abū Ṭālib. In mid-1435 he left for Samarqand and studied mathematics, astronomy, Islamic theology (*kalām*), and the linguistic sciences under **Qāḍīzāde** at the *madrasa* (school) of Samarqand. Among the works he studied was **Niẓām al-Dīn al-Nīsābūrī**'s *Sharḥ al-Tadhkira fīʿilm al-hay'a*', yet another commentary on Ṭūsī's work. Clearly the *Tadhkira* occupied an important place in the school of Samarqand as well as in Shirwānī's education. Shirwānī received his diploma on 13 September 1440. During his education in the *madrasa*, he no doubt participated in astronomical activities, primarily the astronomical observations at the Samarqand Observatory. During his stay in Samarqand, he also wrote a commentary on a work of Islamic law, which he presented to **Ulugh Beg**.

In 1440, after his 5-year long education in Samarqand, Shirwānī returned to Shirwān where he lectured for some time at the *madrasas* there. On the advice of his former teacher Qāḍīzāde, he left for Anatolia (toward the end of the reign of Sultan Murād II [reigned: 1421–1451]) and was warmly received by Çandaroğlu Ismail Bey in Kastamonu. Subsequently, he started teaching in the *madrasas* there. Shirwānī lectured on mathematical and astronomical works, especially those of his teacher Qāḍīzāde, and on *al-Tadhkira*. Muḥyī al-Dīn Muḥammad ibn Ibrāhīm al-Nīksārī (died: 1495) and Kamāl al-Dīn Masʿūd al-Shirwānī (died: 1500) were among his prominent students.

In 1453, Shirwānī dedicated a commentary (*tafṣīr*) on the Qur'ān to the Ottoman Grand Vizier Çandarlı Khalīl Pasha in Bursa. That same year, he presented a work on music (a subdivision of the mathematical sciences) to Sultan Mehmed II. However, later in the year after the conquest of Istanbul, Khalīl Pasha was executed; having lost his patron, Shirwānī returned to Kastamonu. After these events, Shirwānī wrote a work on theoretical astronomy, which was a supercommentary on Qāḍīzāde's *Sharḥ al-Mulakhkhaṣ*. This he presented to Sultan Mehmed II in the hopes of establishing closer ties with the Ottoman court, but he was unsuccessful.

In 1465, Shirwānī set off on a pilgrimage for Mecca; *en route* he continued pursuing scientific activities, first stopping in Iraq and teaching at the *madrasas* in the region. He remained in Mecca for a time, continuing to give lectures. Shirwānī returned to Istanbul, *via* Cairo. Not receiving the attention he thought his due, he returned to his hometown of Shirwān in 1478.

Shirwānī wrote works on literature and linguistics, *kalām*, music, Islamic law, Qur'ānic exegesis, optics, and logic as well as the rational sciences. In the field of geometry, he wrote a gloss (*ḥāshiya*) to Qāḍīzāde's commentary (*sharḥ*) on **Shams al-Dīn al-Samarqandī**'s *Ashkāl al-ta'sīs*. Unfortunately this work is not extant.

In the field of astronomy, *al-Farā'iḍ wa-'l-fawā'id fī tawḍīḥ sharḥ al-Mulakhkhaṣ* was Shirwānī's first important work on theoretical astronomy (*hay'a*), which was a gloss (*ḥāshiya*) on Qāḍīzāde's commentary (*sharḥ*) to **Maḥmūd al-Jaghmīnī**'s *al-Mulakhkhaṣ fīʿilm al-hay'a al-basīṭa*. In order to explain the difficult parts, Shirwānī made use of other commentaries and class notes he took during Qāḍīzāde's lectures at the Samarqand *madrasa*; he completed the work after many rough drafts.

Shirwānī's most noteworthy work on theoretical astronomy is undoubtedly his commentary (*Sharḥ*) to Naṣīr al-Dīn al-Ṭūsī's *al-Tadhkira fīʿilm al-hay'a*, which he completed on 11 January 1475. He emphasized that he wrote his commentary for advanced-level students to whom he lectured in the field of astronomy. His sources were other commentaries, the lecture notes of his teacher Qāḍīzāde, and his own insights.

The *Sharḥ* contains a great deal of information that often has little to do with Ṭūsī's *Tadhkira*. For example, Shirwānī provides comprehensive information about the Turkish calendar as well as other calendar systems. He also discusses Euclid's *Elements* based upon discussions he had with Qāḍīzāde, Ulugh Beg, and students at the Samarqand *madrasa*. Shirwānī also includes a registered copy of his license to teach (*ijāza*) that he obtained from Qāḍīzāde. He has a lengthy discussion on optics (*ʿilm al-manāẓir*), which was considered an ancillary branch of astronomy. He cites numerous works and authors throughout, pointing out his own views when appropriate. Although a thorough analysis of Shirwānī's text has not been yet been made, his style indicates that he was aware of the attempts by **Ibn al-Haytham** and his follower Kamāl al-Dīn Fārisī to combine physical and geometrical approaches within optics, and that this was the subject of ongoing debates in the Samarqand school.

In his *Sharḥ*, Shirwānī discusses Ṭūsī's innovative cosmology in detail. He agrees with Ibn al-Haytham in combining mathematical and natural philosophical approaches; he disagrees with his Samarqand contemporary ˁ**Alī Qūshjī**, who attempted to purge the science of astronomy of Aristotelian principles of physics and metaphysics. Further research into Shirwānī's work promises to provide important information on the history of late medieval Islamic astronomy.

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Shizuki, Tadao

Born **Nagasaki, Japan, 1760**
Died **Nagasaki, Japan, 22 August 1806**

Tadao Shizuki was a translator and commentator of works on natural philosophy; he introduced western (Newtonian) science into Japanese culture and attempted to reconcile its principles with Confucian notions. Shizuki was born into the Nakano family but was later adopted and became an eighth-generation son of the Shizuki family. His was a family of professional translators and interpreters (known as *Tsuji*) who concentrated primarily on Dutch and Japanese sources. Shizuki began practicing this profession in 1776. In the following year, however, he resigned his official position on the grounds of ill health, changed his family name back to Nakano, and began work on his own translations and commentaries. Later, he often used the pen name Ryuen Nakano.

Shizuki was the disciple of Ryoei Motoki who had begun translating western works on astronomy including explanations of the heliocentric system of **Nicolaus Copernicus**. In the Edo era (1603–1867), Nagasaki was one of few ports in Japan through which information about western knowledge could be obtained; Shizuki was one of several scholars who acquired such information. More than a translator, he wrote commentaries about the scientific materials that came into his possession. While his full understanding of the underlying principles remains open to question, Shizuki was instrumental in introducing the concepts of Newtonian mechanics into Japan. He spent some 20 years on this work and devoted the rest of his life to translations of similar materials and linguistic research on the Dutch language.

With his teacher Motoki, Shizuki struggled for most of his life to introduce western concepts of science (derived from Dutch works) into the closed society of Edo Japan. He is perhaps best known for his Japanese translation and commentary on Newtonian principles, *Rekisho Shinsho* (New Treatise on Calendrical Phenomena), completed in 1802. This work was drawn from the writings of **John Keill** but includes many of Shizuki's own ideas. Japanese science of the mid-Edo period was not advanced enough to recognize the need for an understanding of Newtonian mechanics, while an improved calendar was not easily derived from Newtonian dynamics. Shizuki's efforts, while significant for those who came afterward, were not well understood by his contemporaries.

Although he remained somewhat ensconced in classical Chinese modes of inquiry (*e. g.*, Confucian notions of Yin–Yang polarities), Shizuki's commentaries show remarkable originality. Where Keill had started with basic aspects of common experience and moved to Newtonian principles, Shizuki began with cosmological principles and worked toward fundamental mechanical laws. His treatment of **Johannes Kepler**'s third law of planetary motion was fairly accurate. Although certainly not as elaborate or complete, Shizuki's hypotheses regarding the origin of the Solar System were similar to those of **Pierre de Laplace** and **Immanuel Kant**. Japanese terms that Shizuki coined for Newtonian concepts such as gravity and centripetal/centrifugal force became standards that are still in use today.

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Shklovsky [Shklovskii, Shklovskij], Iosif Samuilovich

Born **Glukhov, (Ukraine), 1 July 1916**
Died **Moscow, (Russia), 3 March 1985**

Theoretical astrophysicist Iosif S. Shklovsky was one of the most remarkable personalities and scholars among the Soviet astronomy community of his time. He chose as his own most important contributions the derivation of a reliable distance scale for planetary nebulae and the recognition that the emission from the Crab Nebula is synchrotron radiation (from which he predicted optical polarization, soon after found). Many would also mention his 1964 suggestion that the energy source for quasars is accretion of gas onto giant black holes at the centers of galaxies.

Following high school graduation, Shklovsky spent 2 years working in railroad construction, before beginning the study of physics and chemistry at the Far Eastern State University in Vladivostok, Russia, in 1933. He transferred to Moscow State University [MSU], completing a first degree in 1938, a candidate degree in 1944, and a doctorate in 1949. Shklovsky was excused from active service in World War II because of extreme nearsightedness, and was evacuated with other civilian members of the MSU physics department in 1941, returning to Moscow in 1943 from Ashkhabad (Turkmenistan). He remained associated with MSU for the remainder of his career, founding the radio astronomy department at the Shternberg Institute of Astronomy [MSU] in 1953, and Department of Astrophysics at the new Institute for Space Research in 1969.

Shklovsky's candidate ("The Concept of Electron Temperature in Astrophysics") and doctoral theses dealt with the solar corona. He correctly accepted that the corona was very hot, predicted ultraviolet and X-ray emission (seen in rocket flights in 1947–1949, organized by **Richard Tousey** and **Herbert Friedman**), suggested that it might be heated by hydrodynamic waves, emphasized the coexistence of thermal and nonthermal processes, and suggested that solar radio bursts might be produced by plasma oscillations and the scattering of Langmuir waves to transverse waves.

One of the first topics in radio astronomy beyond the Sun that Shklovsky considered was the detectability of interstellar gas. He concluded in 1952 (independently of H.C. van de Hulst) that neutral hydrogen should have an observable feature. He also calculated the expected millimeter wavelengths from OH and CH molecules accurately enough that they were quickly found when technology was equal to the task 15 to 20 years later.

Shklovsky's 1953 consideration of the newly detected radio emission from the supernova remnant called the Crab Nebula led him to propose that the optical emission might also be synchrotron and so should be polarized. Two Soviet astronomers independently detected this polarization the next year. Shklovsky was also among the first to emphasize that the synchrotron spectrum should continue to X-ray energies, and the emission be extended in space (rather than compact, as in the case of a hot neutron star). This also was found to be the case.

Shklovsky received a 1960 Lenin Prize (then the highest honor in science in the USSR) for the creation of an "artificial comet." He had been thinking about fluorescence in the Earth's upper atmosphere (indeed publishing a paper from the Institute for Atmospheric Physics in 1958) and suggested that sodium vapor shot out from a probe or satellite soon after launch should also fluoresce, making possible sharp enough photographs to permit accurate measurements of trajectories.

Shklovsky went on, in the year of the prize, to formulate a model for synchrotron and other kinds of emission from expanding clouds of relativistic plasma. He applied this to radio galaxies, like Cygnus A and Centaurus A, concluding that they were nonthermal emissions at different evolutionary phases (and not the result of colliding galaxies as had been suggested by **Walter Baade** and **Rudolph Minkowski** when they first saw the optical counterparts), and that their lifetimes must be 10^7–10^8 years, essentially the modern value. The model could also be applied to radio emission from supernova remnants, and Shklovsky predicted that Cassiopea A (remnant of an explosion in about 1680) should be fading at a bit more than 1% per year. This was seen soon after. The interpretation of quasars as accretion on massive black holes came in 1964, soon after the discovery of these sources, and Shklovsky then also pointed out (1965) that quasars and Seyfert galaxies formed a continuum of source types.

The model of planetary nebulae arose as part of another dispute, over whether the gas clouds with stars at their centers came at the beginning or the end of the life of a star. Shklovsky opted (correctly) for "at the end" and, in 1956 pointed out that, if the amount of material ejected as stars like the Sun died was always about the same, then one could find the distances to the observed planetaries, and so the total number that must exist in the Milky Way and thus their birthrates. Again he was essentially right. His other contributions include:

(1) 1963 discovering of the optical variability of the first quasar, 3C273 from archival Russian plates (independent of the discovery made by Harlan Smith and **Dorrit Hoffleit** on Harvard Observatory plates);
(2) coining of the name "relic radiation" for the microwave background left from the Big Bang;
(3) drawing attention to the mix of ionization states represented in quasar absorption spectra as evidence that the absorption clouds in galaxies were distant, from both the quasars and from us, and redshifts therefore are a good distance indicator;
(4) a deep and abiding interest in the possibility of extraterrestrial life and the possibility of contacting it (which he handed on to Nicolay Kardashev, his successor as one of the leader of Soviet radio astronomy);
(5) an assortment of charming, but wrong ideas, like the possibility that one of the satellites of Mars, which seemed to have very low mass for its size, might really be a hollow spacecraft; and
(6) the education and inspiration of two generations of students.

Shklovsky himself was elected to associate membership in the Soviet Academy only in 1966 and never to full membership, though he appeared on the ballot many times. He was, however, honored with memberships, foreign associateships, or medals by the Royal Astronomical Society of Canada, the United States National Academy of Sciences, the Royal Astronomical Society, the Astronomical Society of the Pacific (Bruce Medal, 1972), and the American Academy of Arts and Sciences. He was permitted to travel outside the USSR only sporadically, and so was not able to accept all of these honors in person.

Shklovsky penned the worldwide bestseller, *The Universe. The Life. The Intelligence*. (1962), concerning humanity's place in the Universe. He was a driving force behind a number of landmark domestic and international meetings dedicated to the subject of extraterrestrial intelligence, helping to establish the topics as a legitimate one for scientific discussion.

In total, shklovsky wrote nine books and over three-hundred articles. Most were translated from Russian into foreign languages. Works such as Shklovsky's collection of essays (entitled, in English, *Five Billion Vodka Bottles to the Moon: Tales of a Soviet Scientist*; 1991), include criticisms of the Soviet regime. This book appeared postthumously in Russian only in the Mikhail Gorbachev era.

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Sibṭ al-Māridīnī: Muḥammad ibn Muḥammad ibn Aḥmad Abū ʿAbd Allāh Badr [Shams] al-Dīn al-Miṣrī al-Dimashqī

Born **possibly Damascus, (Syria), 1423**
Died **possibly Cairo, (Egypt), *circa* 1495**

Sibṭ al-Māridīnī was a prolific author of astronomical texts, which were still being used and studied into the 19th century. Little is known with certainty about his life. It is thought that he grew up in Damascus, where his maternal grandfather, ʿAbd Allāh ibn Khalīl ibn Yūsuf Jamāl al-Dīn al-Māridīnī (died: 1406), was the *muwaqqit* (timekeeper in charge of regulating the daily rituals of the Islamic community) of the Umayyad Mosque. Later he traveled to Cairo, where tradition places him as the student of **Ibn al-Majdī**.

Sibṭ al-Māridīnī wrote extensively on mathematics and mathematical astronomy. Like his grandfather, he was especially interested in astronomical instruments. The bio–bibliographical sources list some 25 treatises, many of which exist today in multiple copies. According to the historian al-Jabartī (died: 1822), Sibṭ al-Māridīnī's works on *mīqāt* (ritual timekeeping) and on astronomical instruments were still being studied in the curriculum of Cairo's al-Azhar, one of the preeminent educational institutions in the Islamic world, at about the beginning of the 19th century.

Among Sibṭ al-Māridīnī's works related to astronomy and instruments are:

(1) *Risāla fī al-ʿAmal bi-'l-rub*$^{\grave{A}}$ *al-mujayyab* (on using the sine quadrant);
(2) *Raqā'iq al-ḥaqā'iq* (on calculating with degrees and minutes);
(3) *Zubd al-raqā'iq* (this may be an extract from the previous treatise);
(4) *Muqaddima* (introduction) to sine problems and spherical relations;
(5) *al-Ṭuruq al-saniyya* (on sexagesimal calculations);
(6) *al-Nujūm al-ẓāhirāt* (on the *muqanṭarāt* quadrant);
(7) *Qaṭf al-ẓāhirāt* (apparently an extract from the previous treatise);
(8) *Hāwī al-mukhtaṣarāt* (another discussion of the *muqanṭarāt* quadrant);
(9) *Iẓḥār al-sirr al-mawḍū*$^{\grave{A}}$ (use of a specialized quadrant);
(10) *Hidāyat al-*$^{\grave{A}}$*āmil* (on another kind of specialized quadrant);
(11) *Hidāyat al-sā'il* (on the quadrant mentioned in the previous entry);
(12) *al-Maṭlab* (on the sine quadrant);
(13) *al-Tuḥfa al-manṣūriyya* (on quadrants);
(14) *Muqaddima* (introduction to construction of sundials);
(15) a treatise on the equatorial circle; and
(16) a treatise on the quadrant, astrolabe, and calendar.

Gregg DeYoung

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Sid

❯ **Ibn Sid: Isaac ibn Sid**

Siguenza y Góngora, Carlos (de)

Born **Mexico City, (Mexico), possibly 14 August 1645**
Died **Mexico City, (Mexico), 22 August 1700**

Native-born Mexican scholar Carlos de Siguenza was honored with the title of Royal Cosmographer. His *Libra Astronomica* (1690) includes a rational discussion of comets, the purpose of which was to allay fears inspired by the great comet C/1680 V1.

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Sijzī: Abū Saˁīd Aḥmad ibn Muḥammad ibn ˁAbd al-Jalīl al-Sijzī

Born **Sijistān, (Iran),** ***circa*** **945**
Died ***circa*** **1020**

Sijzī, well known for his contributions to geometry, was also a prolific astrologer and astronomer. We possess few details of his life; his name suggests that he was born in Sijistān. His father, Abū al-Ḥūsayn Muḥammad ibn ˁAbd al-Jalīl, was also a mathematician and astronomer. Parts of Sijzī's life were spent in Sijistān and Khurāsān. In Shīrāz in 969/970, he was present (with **Kūhī**, **Būzjānī**, and others) for the famous observations of meridian transits of the Sun conducted by **ˁAbd al-Raḥmān al-Ṣūfī**. Later in life he became a friend of **Bīrūnī**, who often quoted Sijzī's results in his own works.

Of approximately 20 astrological and astronomical treatises composed by Sijzī, many were compilations and summaries of the works of others, enhanced and systematized by the addition of tables and commentary. His *Jāmiˁ al-Shāhī* contains 13 astrological works, three of which are summaries of treatises by **Abū Maˁshar**. One of these, the *Muntakhab Kitāb al-ulūf*, is an important source of information on Abū Maˁshar's *Book of Thousands*. Another of Sijzī's works, the *Kitāb al-qirānāt* (Book of Conjunctions), may be thought of as a supplement to the *Kitāb al-ulūf*. This material likely originated in Sasanian sources and deals with various topics, including astrological world history. Other astrological contributions include the *Kitāb Zarādusht ṣuwar darajāt al-falak* (The book of Zoroaster on the pictures of the degrees of the zodiac) and *Zāʾirjāt li-istikhrāj al-haylāj wa-'l-kadkhudāh*, a book of horoscopes with tables based on Hermes, **Ptolemy**, Dorotheus, and "the moderns."

Sijzī seems to have had more than a passing interest in astronomical instruments. He wrote a treatise on the astrolabe that contains the geometric "method of the artisans" for drawing azimuth circles on an astrolabe, as well as descriptions of variations in the retes on astrolabes known to him. Bīrūnī describes three astrolabe variants invented by Sijzī, and in the *Exhaustive Treatise on Shadows* he discusses several of Sijzī's contributions to the theory and use of a gnomon. Sijzī's treatise *On [the Fact that] All Figures are Derived from the Circle* contains a geometric description of an instrument that could be used to find the direction of Mecca (the *qibla*). Finally, in his *Introduction to Geometry* he says:

> I made in Sijistān a great and important instrument, a model of the whole world, composed of the celestial spheres, the celestial bodies, the orbs of their motions with their sizes, their distances and their bodies, and the form of the earth, the places, towns, mountains, seas and deserts, inside a hollow sphere provided with a grid. I called it "the configuration of the universe."

Most of Sijzī's 40 mathematical works, including a unique medieval treatise on problem-solving strategies, focus on geometry in the Euclidean style. One of these treatises contains a systematic mathematical approach to establishing the 12 relations that emerge from the transversal figure in spherical trigonometry (the theorem of Menelaus). Although the work is strictly mathematical, Sijzī is explicitly aware of its fundamental importance to mathematical astronomy.

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Silberstein, Ludwik

Born **Warsaw, (Poland), 17 May 1872**
Died **Rochester, New York, USA, 17 January 1948**

Ludwik Silberstein is chiefly remembered for contributions to relativity theory and for numerous textbooks in theoretical physics, mathematics, and the philosophy of science. Ludwik was the son of Samuel and Emily (*née* Steinkalk) Silberstein. He graduated from Cracow Gymnasium in 1890. Silberstein attended the Cracow, Heidelberg, and Berlin universities, receiving his Ph.D. in mathematical physics from the Berlin University in 1894. He married Rose Eisenman in 1895; the couple had three children.

Silberstein's career began at Lemberg, Poland (1895–1897), where he served as an assistant in physics. He was then appointed a lecturer in physics at the University of Bologna (1899–1904) and the University of Rome (1904–1920). In 1920, Silberstein accepted a position as research physicist at the Eastman Kodak Company in Rochester, New York, USA; he became a naturalized US citizen in 1935. Silberstein's principal efforts, however, were devoted to research and explication of **Albert Einstein**'s special and general theories of relativity, along with their philosophical implications, *e. g.*, *Discrete Spacetime* (1936).

During the 1920s, Silberstein explored the observational consequences of the de Sitter model of the Universe (proposed by **Willem de Sitter** as a static solution to Einstein's field equations). Along with others, Silberstein argued that a proportional decrease should be observed in the frequencies of light emitted from increasingly distant sources, giving rise to an apparent velocity–distance relationship (akin to the de Sitter effect). In 1924, Silberstein calculated the expected radius of curvature of the de Sitter model of the Universe (about 40 million parsecs), which he further argued was compatible with globular cluster data (including some blueshifts) supplied by Harvard University astronomer **Harlow Shapley**. But within a few years, **Edwin Hubble**'s demonstration of the velocity–distance relationship for "spiral nebulae" (*i. e.*, galaxies) discredited not only Silberstein's calculations, but also the static de Sitter model itself. Nonetheless, historian J. D. North has written that "Silberstein's were probably the most important contributions to this subject," although they were somewhat "obscured by his polemical style" (on p. 102).

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Silvester, Bernard

Flourished **France, *circa* 1150**

Bernardus Silvestris was one of a number of well-rounded scholars who cultivated a revival of learning during the 12th century. Few personal details are available about Bernard, apart from the fact that he was a master in the schools of Tours, and was associated closely with the school of Chartres, and a friend and literary collaborator of its master Thierry. His major contribution to astronomical literature is the *Cosmographia*, a concise summary of the high medieval understanding of the creation of the cosmos and the geocentric model of the Universe.

The noted medievalist, Charles Homer Haskins, lists Bernardus among the era's great writers. Haskins points out Bernardus's debt to **Macrobius**'s *Commentary on the Dream of Scipio*, and to Thierry of Chartres, to whom the *Cosmographia* is dedicated. A translation of **Ptolemy**'s *Planisphere*, by Peter the Dalmatian, was also addressed to Thierry, providing additional evidence of interest in astronomy there. Bernard was also a master of poetry and prose.

Believing the Universe to be intelligible, the "physici" or natural philosophers of Bernardus's day sought to reconcile observation with revealed religion and classical sources. In the universities of the era, increasing attention was being paid to the *quadrivium* (arithmetic, geometry, music, and astronomy), over the foundation courses known as the *trivium* (grammar, rhetoric, and logic). Bernardus, who wrote at midcentury, stands as a representative scholar of his day, associated with a revival of Greco–Roman natural science, and as a master and advocate of the language arts.

The *Cosmographia* is divided into two sections, Megacosmos and Microcosmos. The former deals with the Universe at large, and the latter with our place in it.

In Megacosmos, we are told that the Universe, stars, and planets, are spherical and rotate upon an axis. Although it is eternal, this Universe was not always orderly and harmonious. Primary matter (*Hyle*) was in a state of chaos or conflict, subject to "random eddies." The divine intellect, *Noys*, brings order and harmony to the chaotic primal Universe. Natural philosophy (*Physis*), whose daughters are theory and practice, contemplates the Universe and generates knowledge. When *Noys* brought organization and perfection of the Universe, the simple and undivided became complex and differentiated. As part of the ordering process, the elements became distinguishable from primal matter and from each other, and eventually, the genera of plants and animals could be subdivided into species.

Bernardus considered the Sun to be one of seven planets. The Moon reflects the light of the Sun, and causes the tides. Bernardus noted that Ptolemy referred to the Moon as a planet of the Sun, and credited the Persians with first charting the heavenly bodies. Additional evidence of observational astronomy in the *Cosmographia* can be found in its mention of the major constellations and their locations. This catalog is presented in a mnemonic fashion, rather like a litany. The Milky Way is said to be a region "whose radiance is produced by clustering stars." The ecliptic is slanted with respect to the Equator; we can delimit it by noting the solstices. This accounts for changes of season.

The Earth stands at the center of a spherical Universe, within which exist four basic elements: earth, water, air, and fire. Each tends toward a place, with fire seeking the heights, earth the depths, and so forth. Energy is imparted from the outermost sphere to the inferior ones, causing them to rotate. It is noteworthy that the energy that is being imparted is energy of motion. The sublunary sphere, comprising the atmosphere and the Earth with its seas and landmasses, is the least orderly. This conforms to the sorts of observations possible in Antiquity and the Middle Ages. The courses and configurations of the stars and constellations would have appeared more regular than those of the planets.

As did **Plato**, Bernard referred to the Universe as a creature or animal, giving it both matter and a world-soul or spirit. In the Microcosmos, we see how the human race mirrors the cosmos, having a nature both spiritual and material. Astronomy can therefore be a key to self-understanding, and conversely, the understanding of the human condition can point to eternal cosmic truths. Indeed, the future can be predicted by "starry cyphers." Consequently, parts of the Microcosmos are astrological, being devoted to the influences of the various planets – Mars is associated with war, Venus with love, and so forth. In his closing sections, Bernardus discussed various human faculties.

Bernardus's model of the Universe was geocentric, and all conjectures and observations had to be reconciled with that basic premise. However, the notion that energy filters down from the stars, and the idea that the elements developed from primal, undifferentiated matter, strike more modern chords. Perhaps most important, there is a strong sense in the *Cosmographia* that physical laws exist uniformly throughout the Universe, and that we can indeed know them. *Physis*, or knowledge of that universe, depends upon both of her daughters, theory and practice.

C. Brown-Syed

Alternate name

Bernardus Silvestris

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Sima Qian

Born **Longmen (Hancheng, Shaanxi), China, *circa* 145–135 BCE**
Died **China, *circa* 90 BCE**

Sima Qian was a Chinese historian and astronomer in the western (former) Han dynasty who helped devise a calendar in which a 13-lunar month occurred as needed, rather than always at the end of the solar year. His public name was Zichang. Sima Qian's father, Sima Tan, was also a historian and astronomer. After the death of his father in 110 BCE, Sima Qian succeeded to his father's position as *Taishiling* (historiographer and astrologer royal) in 108 BCE. In 104 BCE, Sima Qian took part in the major calendar reform of that year and also started to write a history. In 99 BCE, Sima Qian defended at court general Li Ling, who had surrendered to a vastly superior foreign force. Emperor Wu was offended by Sima Qian's outspokenness, and as a result in 98 BCE, Sima Qian was arrested and castrated for attempting to deceive the emperor. After his release, Sima Qian continued to write history, and finally completed the *Shiji* (Grand Scribe's records), a monumental work of Chinese history, in about 91 BCE.

Classical Chinese calendars are luni-solar calendars, which can be traced to the Shang (Yin) dynasty (mid-16th century to 1046 BCE). This is inferred from the oracle bone inscriptions dating from the 13th to 11th centuries BCE. The development of calendrical science in the western Zhou dynasty (1046 BCE–771 BCE) and the Chunqiu (Spring and Autumn) period (770–476 BCE) is still awaiting further research. By the end of the Zhanguo (Warring States) period (475–221 BCE), the 19-year cycle of intercalation, in which 7 intercalary months are inserted at intervals, was already in use, and the length of a year was considered to be 365 days. This type of calendar was called a *Sifen* calendar (quarter-remainder), named after the fraction of the length of a year.

At the beginning of the western Han dynasty (208–206 BCE), the Zhuanxu calendar, a kind of *Sifen* calendar of the previous Qín dynasty (221–206 BCE) was still used. In this calendar, an intercalary month was put at the end of the relevant year. A fragment of the calendar for the year 134 BCE was excavated in 1972 in Shandong province proving the calendar's actual use at the time. As an exact calendar was considered to be a symbol of the dynasty's authority, a calendar reform was proposed in 104 BCE under the reign of Wudi (Emperor Wu; reigned: 141–87 BCE). The emperor ordered that this year should be the first year of the new era *Taichu*, or grand inception.

Intellectuals, including Sima Qian, discussed the required calendar reform. After the proposal of several calendars, the one made by Deng Ping, the same as one devised by one Luoxia Hong, was finally adopted. It was used from the fifth month of the first year of the *Taichu* reign period (104 BCE) as the *Taichu* calendar. At that time, Sima Qian was the director of the Bureau of Astronomy and the Calendar, and Deng Ping was appointed deputy director. Another contributor, Luoxia Hong, is credited with the invention of the armillary sphere.

In the *Taichu* calendar, the 19-year cycle of intercalation was used as before, but the length of a year was changed to 365 385/1539 days, and that of a synodic month to 29 43/81 days. Here, the denominator 81 was selected because it was the same as the tone of the fundamental pitch pipe. In the correlative cosmology of the time, the tonal system, the calendar, and even measures of volume were all interrelated. The accuracy of the length of the year and the month in the *Taichu* calendar is almost the same as that of the *Sifen* calendar. One merit of the *Taichu* calendar was the new method of intercalation. By the beginning of the western Han dynasty, one year from the winter solstice to the next winter solstice was divided into 24 equal periods, and 24 points of time called *jieqi* ("*qi*-nodes") were established. It may be noted here that the *jieqi* in the modern East Asian classical calendars are the points in time when the Sun passes through those points whose longitude is a multiple of 15°. In the *Taichu* calendar, alternative 12 points called *zhongqi* ("central *qi*-nodes") were selected from the 24 *jieqi*, and the name (serial number) of a month was determined by the *zhongqi* that was included in that month. As the length of a synodic month is a little shorter than the interval of the *zhongqi*, sometimes a month without a *zhongqi* is produced, and such a month becomes an intercalary month. This method of intercalation was followed by later Chinese calendars.

At the end of the western Han dynasty, Liu Xin (died: 23) added to the calendar a method for the prediction of lunar eclipses, a method to calculate the position of the five planets, and the concept of the grand origin epoch. This enlarged calendar is known as the *Santong* calendar, and is recorded in the monograph on the calendar in the *Han shu* (History of the former [western] Han dynasty) (*circa* 78) by Ban Gu (32–92).

There is one curious matter in Sima Qian's *Shiji*. At the end of the monograph on the calendar, Sima Qian describes a calendrical system called *Lishu jiazi pian*. Oddly, it is not the *Taichu* calendar, but a kind of *Sifen* calendar. It may be that it is one of the rejected calendars proposed at the time of the calendar reform. Yukio Ôhashi suspects that Sima Qian tried to oppose the farfetched denominator used in the *Taichu* calendar. Comparing the length of a year and a month, converted into decimal fractions in these calendars (which are almost identical and equally inaccurate) in the *Sifen* calendar, 1 year = 365.25 days, and 1 month = 29.53085 days; in the *Taichu* calendar, 1 year = 365.2502 days, and 1 month = 29.53086 days.

From the above comparison, it is clear that the fraction used in the *Taichu* calendar was artificially selected, for metaphysical reasons, using the value of the *Sifen* calendar without any attempt to adjust it by observation. It is this artificial fraction that might have been opposed by Sima Qian. As far as the lengths of a year and a month are concerned, those of the *Sifen* calendar were recognized even by the compilers of the *Taichu* calendar. Although the *Han shu* relates that several astronomical observations were made at the time of the calendar reform, they were for the determination of a better epoch for a calendar of the same accuracy, and not for the revision of the length of a year and a month. The inaccuracy of the *Sifen* calendar was noticed already by the eastern (later) Han dynasty (25–220), and some astronomers attempted to revise the value at that time.

Alternate name

Ssu-Ma Ch'ien

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Simplicius of Cilicia

Born **Cilicia, (Turkey), *circa* 490**
Died **probably in Athens, (Greece), *circa* 560**

A mathematician primarily, Simplicius wrote one of the most detailed accounts of **Eudoxus**'s theory describing the motions of the planets.

It is often the case that Simplicius is confused with a pope and saint by the same name who died in 483, but the two were in no way related. The astronomer and mathematician Simplicius was born in Anatolia (now part of Turkey), which at the time was a Roman province and had been since the first century BCE. The first information we have on Simplicius is that he studied philosophy in Alexandria, at the school of Ammonius Hermiae. Ammonius himself was a student of **Proclus** and wrote extensive commentaries on **Aristotle**, which presumably influenced Simplicius to do the same. He later traveled to Athens to study under a Neoplatonist, Damascius, who also taught the works of Proclus.

In 529, the Christian Emperor Justinian closed all pagan schools in the Roman Empire. Simplicius then accompanied Damascius and others from the school to Persia to serve the Persian king Khosrow I, who held to traditional religion and was fighting the Roman legions on the Euphrates River and had been since before Justinian had become emperor. However, in 532 Justinian and Khosrow signed a peace accord, and this allowed Simplicius to return to Athens. In fact, the treaty reportedly was explicit about the fate of the philosophers, and allowed them complete freedom in their work and lives upon their return to the empire, though this point has been challenged historically. It is thought that Simplicius spent the rest of his life in Athens; however, his writing style changed at this point, suggesting that either of his own free will or due to political pressure, he no longer lectured.

Simplicius' contributions to mathematics were extensive and tend to overshadow his contributions to astronomy. In addition, many of his writings were actually commentaries on the writings of other mathematicians, philosophers, and astronomers, most notably Aristotle. Simplicius' commentary on Aristotle's *Physics* is of interest in that it contains considerable extracts from **Eudemus**' *History of Geometry*, which included **Hippocrates**' quadratures of "lunes" or crescent-shaped figures and an account of Antiphon's attempt to square the circle. This is an important historical link to Hippocrates' work.

In his commentary on Aristotle's *De caelo*, Simplicius gave the most detailed account that has survived of Eudoxus' famous theory of concentric spheres, a theory that was used to describe the motions of the Sun, Moon, and planets. Simplicius actually quoted largely from **Sosigenes**, the Peripatetic who, himself, drew from Eudemus' *History of Astronomy*. This Simplicius extract also contains modifications made to the model by **Callippus** and Aristotle. The theory suggested that the motion of each planet was produced by the rotation of four concentric spheres, where the inner spheres revolve around a line that is fixed in the next sphere enclosing it. The outermost sphere represented a daily rotation, while the one next to it represented motion along the Zodiac. There were two other spheres, and this set of four spheres was used to represent the motion of just a single planet. So each planet had four concentric spheres, while the Sun and the Moon only had three.

Simplicius also wrote a commentary on Euclid's *Elements, Book I*, which was later quoted by **Nayrīzī**. Simplicius referred to problems relating to gravity and expressly mentioned the work of **Archimedes** on centers of gravity. Simplicius added his own explanatory comments to this regarding the definition of the center of gravity.

Ian T. Durham

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Sīnā

➜ **Ibn Sīnā: Abu ʿAli al-Ḥusayn ibn ʿAbdallah ibn Sīnā**

Sitter, Willem de

Born **Sneek, the Netherlands, 6 May 1872**
Died **Leiden, the Netherlands, 20 November 1934**

Dutch mathematical astronomer Willem de Sitter gave his name to one of the first solutions to **Albert Einstein**'s equations of general relativity, which showed that a universe containing very little matter would, in some sense, expand, and so prepared the way for **Edwin Hubble**'s discovery of that expansion (though a different solution in fact applies). De Sitter was the son of a judge, Lamoraal U. de Sitter and Catharine Th. W. Bertling. He received his early education at Arnhem, the Netherlands, where his father was President of the Court. De Sitter studied at the University of Groningen, primarily in mathematics, under **Jacobus Kapteyn**, with whom he maintained a lifelong friendship and scientific collaboration, receiving a Ph.D. in 1901 for work involving observations of the satellites of Jupiter, made in Cape Town, South Africa (1897–1899). In Cape Town, de Sitter also met and married Eleonore Suermondt. They had three sons and two daughters.

From his position as a staff member at Groningen, de Sitter was appointed to a professorship of astronomy at Leiden University in 1908, where he became director of the observatory in 1919, holding both positions until his death. He reorganized the Department of Astronomy at Leiden, adding a department for astrophysics, and observational facilities at the Union Observatory in Johannesburg, South Africa.

De Sitter has become best known for his work on cosmology, but the earliest part of his career and much of his later life were devoted to celestial mechanics and astrometry. In his thesis of 1901, he discussed heliometer observations of Jupiter's inner moons made at the Cape Observatory, leading to an improved determination of the masses of these satellites. In a subsequent work (*New Mathematical Theory of Jupiter's Satellites*) de Sitter presented a comprehensive analysis of the observations of the satellites made since 1668. His wide knowledge of celestial mechanics also allowed him to present comprehensive discussions of the complicated interrelations among the phenomena from which the major astronomical constants are derived, in particular the combination of results from geodetic and gravity measurements with those from astronomical observations. In 1927, he published *The Most Probable Values of Some Astronomical Constants*. A second paper *On the System of Astronomical Constants*, edited by de Sitter's pupil **Dirk Brouwer**, was posthumously published in 1938. These constants include both the shape of the Earth and numbers for the length of the astronomical unit and the masses of the planets.

In order to arrive at a system of fundamental declinations, free from the systematic errors due to atmospheric refraction and flexure of the telescope that always have plagued meridian observations, de Sitter initiated in 1930 a pilot expedition to Kenya, where, right on the Equator, declinations were made by measuring the distance along the horizon between the rising and setting points of a star, which gives an angle that is two times the complement of the declination.

De Sitter was among the very first to realize the importance of Einstein's work on relativity for astronomy, and he contributed much to the introduction into the English-speaking countries of Einstein's work during World War I. He first discussed, in 1911, the small deviations in the motions of the Moon and the planets still left in the context of classical dynamics. In 1916 and 1917, de Sitter presented to the Royal Astronomical Society a series of three papers on "Einstein's Theory of Gravitation and its Astronomical Consequences." Because there was almost no communication between Germany and England during World War I, these papers were instrumental in introducing general relativity to the English scientific community, and they played an important part in the decision made by **Arthur Eddington** and others to send expeditions to observe the solar eclipse of 1919 to look for the small shifts in the positions of stars predicted by Einstein's theory. In the context of his cosmological work, de Sitter introduced a solution to the fundamental equations that define the properties of the Universe;

it soon became known as the de Sitter universe (or de Sitter space), an alternative to Einstein's solution, provided the density of matter in the Universe could be considered negligible and the Universe be allowed to expand. De Sitter's solution predicted systematic redshifts in the spectra of distant objects (though a quadratic relationship rather than a linear one, which was sought by several colleagues).

De Sitter was elected president of the International Astronomical Union for 1925–1928. One of his major concerns (shared by Eddington and others) was to reintegrate the international community, and he succeeded in extending invitations to the 1928 General Assembly in Leiden to astronomers from Germany and others of the "Central Powers," though some of these nations were not admitted to the union until after World War II. De Sitter was the author of a booklet on the history of the Leiden Observatory (1633–1933) and a founder (in 1921) of the journal *Bulletin of the Astronomical Institutes of the Netherlands*. It, in turn, was merged in 1969 with journals from France and Germany to form a single European journal, *Astronomy and Astrophysics*.

De Sitter received medals from the Royal Astronomical Society (London) and the Astronomical Society of the Pacific, as well as a number of honorary degrees.

The archives of Leiden Observatory have a collection of de Sitter's notes and letters.

Adriaan Blaauw

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Sizzi, Francesco

Flourished **Italy, 1611**

Florentine Francesco Sizzi wrote *Dianoia Astronomica*, a pedantic response to **Galileo Galilei**'s *Sidereus Nuncius*. Sizzi argued that the Galilean satellites could not exist, because they would cause the quantity of "planets" to exceed the favored number seven.

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Skjellerup, John Francis

Born **Cobden, Victoria, (Australia), 16 May 1875**
Died **Melbourne, Victoria, Australia, 6 February 1952**

John Skjellerup independently discovered or recovered eight comets, of which five bear his name. He was also a dedicated variable-star observer from both South Africa and Australia.

Frank Skjellerup, as he liked to be known, the son of a Danish immigrant farmer, Peder Jensen Skjellerup and his British-born wife Margaret (*née* Williamson) Skjellerup, was the tenth of 13 children. When he was still a small boy his father died. As a result, the day before his 14th birthday, Frank left school and began working as a messenger for the Victorian Post Office. He trained as a telegraph operator, and when the South African Government began recruiting telegraphers in Australia, Skjellerup was one of those selected, arriving in Cape Town in early 1900. Although he spent the rest of his working life in South Africa, when he retired in 1923 he and his wife Mary returned to Australia, settling in Melbourne.

Inspired by the Great Daylight Comet of January 1910 (C/1910 A1) and comet 1P/Halley, Skjellerup became interested in astronomy in 1910, and purchased a 7.6-cm alt azimuth-mounted refractor. In 1922, he replaced this with a Cooke refractor of identical aperture and style of mounting. These telescopes and Zeiss 8 × binoculars were his main observing aids throughout an observational career spanning more than three decades.

In 1911, Skjellerup began systematically searching for new comets. At first he used the Zeiss binoculars, but toward the end of the decade substituted the 7.6-cm refractor. Skjellerup made his first comet discovery on 11 September 1912, only to learn that Walter Frederick Gale (1865–1945) of Sydney had detected this comet (C/1912 R1) several days earlier. His second discovery would also bring disappointment. On 31 October 1915 he found a new comet and immediately notified the Cape and Union observatories, only to learn later that it was none other than the return of periodic comet 7P/Pons–Winnecke. On the morning of 19 December 1919, Skjellerup discovered his third comet (C/1919 Y1) while searching for the variable star RS Librae. No prior discovery claims emerged, and he finally secured a comet bearing his name.

Nearly a year later, on 11 December 1920, Skjellerup made his next discovery (C/1920 X1). In fact, another Cape Town amateur, Charles Clement Jennings Taylor (1861–1922), had detected this comet on 8 December, but Taylor was ill and recorded the wrong position for it. Taylor's incorrect announcement prevented confirmation by others, and Skjellerup received credit for the discovery. Skjellerup's next comet came along on 16 May 1922, but was later shown to be the same comet that **John Grigg** discovered in 1902, comet 26P/Grigg–Skjellerup. Comet 26P has one of the shortest periods of any known comet (5.1 years) and was extensively studied by the Giotto space probe. This was followed by Skjellerup's discovery of comet C/1922 W1 on 26 November 1922.

Although Skjellerup returned to Australia in 1923, it was not until 4 December 1927 that he discovered his next comet. Awakened by an unusual sound (made by his cat), he noticed that it was a beautiful clear night, could not resist the temptation to do a little comet-seeking, and discovered C/1927 X1. An observer at La Plata, Argentina, independently discovered the same comet and was granted status as a codiscoverer. Skjellerup's last independent discovery, C/1941 B2 on 21 January 1941, had been discovered 6 days earlier by South African amateur Reginald Purdon DeKock (1902–1980). In recognition of his various discoveries, Skjellerup was awarded four Donohoe Medals and two Donovan Medals. In addition to the six comets that he independently discovered, and his 7P/Pons–Winnecke recovery, Skjellerup observed at least 18 other known comets.

Skjellerup's first casual observations of variable stars were conducted in 1910, but when he and fellow-amateur Arthur William Long (1874–1939) were granted permission to use the Cape Observatory's 15.2-cm and 17.8-cm refractors, his annual tallies increased rapidly. After returning to Australia, he continued a more restricted program. During the 12-year period, from 1916 to 1927, Skjellerup made 6,773 estimates of 121 different variable stars, mainly of Mira-type variables, and also of four semi-regular stars and two R Corona Borealis stars. In addition, he recorded Nova Aquila 1918.

In addition to his observational work, Skjellerup served as secretary–treasurer, and eventually for several years as vice president, of the Cape Astronomical Association. He also served as president of the Astronomical Society of Victoria, for 3 years.

Skjellerup was survived by his wife, Mary. There were no children from their marriage.

Skjellerup's observing logs and scrapbooks are in the possession of the author of this entry.

Wayne Orchiston

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Slipher, Earl Carl

Born **near Mulberry, Indiana, USA, 25 March 1883**
Died **Flagstaff, Arizona, USA, 7 August 1967**

American optical astronomer Earl Slipher obtained large numbers of photographs of the planets that were used to demonstrate changes in the patterns and colors of Martian clouds and changes in the rotation period of the Great Red Spot on Jupiter (meaning that it could not be anchored to a solid surface below).

Slipher was the son of David Clark and Hannah App Slipher and the younger brother of astronomer **Vesto Slipher**. He earned B.A. (1906) and M.A. (1908) degrees from the University of Indiana and received honorary degrees from the University of Arizona and Northern Arizona State University. Slipher married Elizabeth Tidwell in June 1919; they had one daughter, Capella, and one son, Earl, Jr.

Slipher began his astronomical career by accompanying his astronomy professor at Indiana, **John Miller**, on a solar eclipse expedition to Spain in 1905. Slipher participated in four other eclipse expeditions. From 1906 to 1908 he was the Lawrence Fellow at Indiana, whereby an astronomy graduate could intern at Lowell Observatory for a year or two and receive a master's degree. **Percival Lowell** supported an expedition headed by professor **David Todd** of Amherst in 1907 and sent Slipher as Todd's assistant to observe Mars from the Andes in Peru. This expedition launched Slipher's career as a lifelong planetary observer.

Slipher was employed permanently at Lowell Observatory upon his return from Peru and remained there for his entire career, becoming a well-recognized expert on the photography of planets. He pioneered the technique of printing planetary photographs through multiple short-exposure negatives to record enhanced surface or atmospheric details seen during moments of exceptional seeing. Under Lowell's direction, Slipher participated in the search for planet X, but came to consider the project a futile effort.

Slipher eventually headed three Mars expeditions to the Southern Hemisphere at the Lamont–Hussey Observatory at Bloemfontein, South Africa, in the years 1939, 1954, and 1956. In 1954, when Mars approached unusually near to the Earth, he was instrumental in organizing and served as cochair of the International Mars Committee that coordinated observations of Mars from observatories all over the world. The committee included such well-known experts as **Harold Urey**, **Gerard de Vaucouleurs**, and amateur visual observer Thomas R. Cave, Jr. (1923–2003).

In 1960, Slipher headed a US Air Force project at Lowell to update all ground-based observations of Mars. The results were summarized in two books, *The Photographic History of Mars (1905–1961)* and *A Photographic Study of the Brighter Planets*. In 1911, he received a medal from the Astronomical Society of Mexico for his early work on eclipses.

Slipher was exceptionally active in civic affairs. He served two terms as mayor of Flagstaff, as chair of the Arizona Good Road Committee, and as representative of Coconino County in both houses of the Arizona legislature. From 1935 to 1939, Slipher was a member of the board of Flagstaff State Teachers College, now Northern Arizona University. During World War II, he served as chair of the Coconino County Selective Service Commission.

Henry L. Giclas

Selected Reference

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Slipher, Vesto Melvin

Born **near Mulberry, Indiana, USA, 11 November 1875**
Died **Flagstaff, Arizona, USA, 8 November 1969**

American spectroscopist Vesto Slipher is now remembered primarily as the person who obtained the spectra and measured the first radial velocities of the spiral nebulae showing that most were receding from the Earth. **Milton Humason** extended Slipher's measurements to more-and-more distant galaxies; this led to **Edwin** Hubble's discovery of the velocity–distance relation and, therefore, the expansion of the Universe.

Slipher was the son of David Clark and Hannah App Slipher; his brother, **Earl Slipher**, also was an astronomer who also spent most of his career at Lowell Observatory, being associated primarily with photography of the giant planets and their satellites. Vesto received his degrees from the University of Indiana (A.B.: 1901; A.M.: 1903; Ph.D.: 1909; honorary Ph.D.: 1929), and honorary degrees also from the University of Arizona, University of Toronto, and Arizona State University. Slipher was hired by **Percival Lowell** for his observatory partly to study the spiral nebulae, which Lowell then believed to be solar systems in the process of formation. Slipher originally shared this belief, but was later led by his own work to regard them as independent galaxies, as proved to be the case.

Slipher used a spectrograph built by **John Brashear** on the Lowell 24-in. telescope. Among his discoveries were the rotation period of Uranus (with Lowell: 1912), the details of the rotation of the rings of Saturn, the strong absorption bands in the spectra of the giant planets (later shown by **Rupert Wildt** to be due to methane and ammonia), the large velocities of the stars in globular clusters, and the fact that the spectrum of the diffuse material around the Pleiades is identical to that of the stars (also 1912). Soon after, he identified several other members of the class we now call reflection nebulae, recognized at about the same time by **Edwin Hubble**. By studying aurorae close to twilight, Slipher was able to correlate their intensity with solar activity. He was also interested in the background light of the night sky, discovered shortly before by **Simon Newcomb**.

The work for which Slipher is best known began in December 1912, when (in an exposure stretching across two nights) he obtained the first spectrogram of the Andromeda Nebula (M31) in which absorption lines (which he recognized as very much like those in solar-type stars) could be seen and have their velocities measured. He found M31 to be approaching the Solar System at about 300 km/s, the largest velocity measured up to that time. By 1925, Slipher had pushed his telescope–spectrograph combination to its limits, obtaining a radial velocity of +1800 km/s for NGC 584.

Slipher became assistant director of Lowell Observatory in 1915 (when Lowell could no longer be on site most of the time), acting director in 1916 (upon Lowell's death), and director in 1926, after which his own astronomical activity declined a good deal. He retired in 1953 and held the title director emeritus until his death. Slipher married Emma R. Munder at Frankfort, Indiana, on 1 January 1904, and they had two children, Marcia and David.

Among the honors Slipher received were the Lalande Prize of the Paris Academy of Sciences (1919), the Gold Medal of the Royal Astronomical Society (London, 1932), and the Draper Gold Medal of the United States National Academy of Sciences (1932). He was elected to Phi Beta Kappa from Indiana, and was a member of the scientific research honorary Sigma Xi and of most of the astronomical and scientific societies in the United States. At the time of Slipher's death, many had forgotten his most important contributions to astronomy; a short death notice in *Physics Today* mentions only that he had supervised the work by **Clyde Tombaugh** that led to the discovery of Pluto.

Henry L. Giclas

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Slocum, Frederick

Born **Fairhaven, Massachusetts, USA, 6 February 1873**
Died **Middletown, Connecticut, USA, 4 December 1944**

American astrometrist Frederick Slocum contributed to the early 20th-century effort to measure parallaxes for large numbers of stars. The son of Frederick and Lydia (*née* Jones) Slocum, Frederick earned bachelor's (1895), master's (1896), and doctoral (1898) degrees from Brown University. Slocum married Carrie E. Tripp in 1899; the couple had no children.

Slocum was appointed assistant professor of astronomy at Brown University (1900–1909). He received additional training in astrophysics at Potsdam Observatory and returned to teach that subject at Yerkes Observatory (1909–1914). In 1914, Slocum was appointed professor of astronomy and director of Wesleyan University's Van Vleck Observatory, and apart from two years spent as a visiting instructor in nautical science at Brown University (1918–1920), remained in those positions until his retirement.

Slocum participated in efforts coordinated by Allegheny Observatory director **Frank Schlesinger** to determine stellar parallaxes from photographs made with Van Vleck's 20-in. refracting telescope; this work was published in 1938. Active in professional organizations, Slocum was elected vice president of Section D of the American Association for the Advancement of Science and vice president of the American Astronomical Society. He was also the recipient of an honorary degree (Sc.D., 1938) from Brown University.

Jordan D. Marché, II

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Smart, William Marshall

Born **Doune, Perthshire, Scotland, 9 March 1889**
Died **Lancaster, England, 17 September 1975**

William Smart was an expert on spherical astronomy.

Smart, son of Peter Fernie Smart and Isabella Marshall Harrower, acquired his interest in science and mathematics while attending McLaren High School in Callender, Scotland. Smart's high academic abilities won him a scholarship to Glasgow University (1906–1911). He graduated with first class honors and was awarded the Cunninghame Medal for Mathematics.

Smart pursued postgraduate studies at Trinity College, Cambridge, and received his doctorate in pure and applied mathematics (1914). He was awarded several other prizes, including a First in Part I of the mathematical *tripos* examination. During World War I, Smart became an instructor–lieutenant at the Royal Naval College, Greenwich, where he developed a lifelong interest in navigation. In 1919, he returned to Cambridge as John Adams Astronomer and chief assistant at the university observatory, under the supervision of **Arthur Eddington**. Smart began to investigate stellar motions and the structure of our galaxy, which culminated in a series of papers (and more than one textbook). His most widely utilized volume, *Textbook on Spherical Astronomy*, was first published in 1931. In 1919, Smart married Isabel Macquarie Carswell; the couple had three sons.

In 1937, Smart returned to his native land upon appointment as Regius Professor of Astronomy at the University of Glasgow, succeeding Ludwig Becker. Conditions at the urbanized Dowanhill Observatory had deteriorated, however, and under Smart's directive, a smaller students' observatory was erected at Gilmore Hill (1939). But his Scottish career was interrupted by World War II; he taught celestial navigation to Royal Air Force cadets. Afterward, the postwar transformation of astronomical research effectively put an end to Smart's line of investigation. Increasingly, he devoted himself to the writing of both advanced textbooks – his *Celestial Mechanics* appeared in 1953 – and a series of popular works, including an account of the discovery of Neptune. Smart lectured widely on astronomy, and acquired many professional distinctions, notably as secretary (1931–1937), vice president (1937–1938), and later president (1949–1951) of the Royal Astronomical Society. He retired from his position in 1959.

Smart's adherence to the mathematical rigors of fundamental astronomy was not an idle pursuit. Although no longer a subject at the forefront of research, its principles nonetheless establish the basis on which virtually all other types of astronomical observation must eventually rest.

Jordan D. Marché, II

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Ovenden, Michael W. (1977). "William Marshall Smart." *Quarterly Journal of the Royal Astronomical Society* 18: 140–146.

Smiley, Charles Hugh

Born **Camden, Missouri, USA, 6 September 1903**
Died **Providence, Rhode Island, USA, 26 July 1977**

After receiving his Ph.D. in astronomy at the University of California in Berkeley, American mathematician Charles Smiley traveled and worked extensively in Europe, including on assignments at the Royal Greenwich Observatory, where he worked with **Leslie Comrie** and **Andrew Crommelin**, and at Cracow, Poland, where he did orbital calculations with **Thaddeus Banachiewicz** for the then recently discovered Pluto. On his return to the United States, Smiley accepted a professorship at Brown University, where his primary research involved observing 15 solar eclipses. In 1937, Smiley successfully photographed the zodiacal light during a total solar eclipse. He used a Schmidt camera of his own design and construction, a very early application of such cameras.

Also interested in ancient astronomies, Smiley in 1960 published a correlation of the Mayan and Christian calendars based exclusively on astronomical evidence. He extended this knowledge to a description of the astronomical dates identified on the Mayan codices located in Dresden, Paris, and Madrid, demonstrating their use in predicting solar eclipses anywhere on the Earth over an 8-century period.

Smiley was an active supporter of amateur telescope makers and amateur astronomers; he served as president of the American Association of Variable Star Observers.

Thomas R. Williams

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Smith, Sinclair

Born **Chicago, Illinois, USA, 1899**
Died **Pasadena, California, USA, 1938**

Sinclair Smith is best known to astronomers for his measurement of the gravitating mass of the Virgo cluster of galaxies in 1937, which confirmed the very large mass-to-light ratio that had been found for the Coma cluster by **Fritz Zwicky** in 1933. Smith is a less familiar name in 20th-century cosmology for two reasons: First, his work was largely in the area we would now call instrumental physics, rather than observational astronomy, and, second, he died tragically early, of cancer.

Smith received his bachelor's degree from the California Institute of Technology (Caltech) in 1921 and his Ph.D. in 1924, also from Caltech, for work with **John Anderson** on electrically exploded wires as a method of obtaining laboratory spectra at high excitation and ionization energies. He remained in the physics laboratory of Mount Wilson Observatory the rest of his life, apart from a year (1924/1925) at the Cavendish Laboratory in Cambridge, England. A true Californian, if not quite native, Smith was an enthusiastic owner and sailor of small boats, in company with Thomas Lauritsen and other Caltech colleagues.

Smith was clearly a widgeteer par excellence. His outstanding contribution to exploding wire research was a spectrograph with microsecond temporal resolution. It focused the spectrograph slit on a rotating mirror, which, in turn, shined the light sequentially across photographic film, producing a record of the evolution of the spectrum of the wire as it vaporized. Rotating mirrors recur in several of his later devices.

Next came a vertical seismometer and an optical oscillograph. This latter device provided a permanent record of rapidly changing electric current by passing the current through a solenoid wrapped around a C_2S cell between crossed polarizers. A collimated beam of white light was shown through the device, through a prism, onto a rotating mirror, and so on to the film. As the current varied, changing the cell's rotation of the plane of polarization versus wavelength, a varying pattern of light and dark fringes was recorded on the film.

Radiometers were Smith's next major love. He studied their sensitivity as a function of temperature, using liquid air as a coolant, and adapted them for use as detectors in stellar photometry and for a laboratory registering microphotometer, also with a rotating mirror. The latter, a coworker gently recalled, was "not competitive" with photoelectric cells and other technologies.

Smith also developed a more conventional stellar photometer, with photoelectric cell and Hoffman electrometer. Attached to the 100-in. telescope, it could produce a current of 500 electrons per second for a 14th magnitude star and determine its flux to 1% in 21 s.

Smith's expertise in measurement of light intensity led to a collaboration with **Richard Tolman** to consider experimental tests of the various possible interpretations of the wave particle dualism. The device they considered appears never to have been built, perhaps because they concluded that it could not distinguish an early version of the absorber theory of radiation from more conventional interpretations. This appears to have been Smith's most nearly theoretical paper.

Perhaps the most productive widget was an *f*/l quartz spectrograph, one of the very first to use a Schmidt camera. He turned this spectrograph toward M32, along with a Wollaston prism (presumably also his own device), and the 100-in. telescope was made into an interferometer with a dark strip across its tube. He concluded that the Galaxy was unpolarized, had a slightly resolved (0.8″) nucleus, and showed no gradient of spectral type across its surface. These observations led him to rule out several now-forgotten models of elliptical galaxies in favor of the giant star clouds we all now accept.

The spectrograph was fast enough to record on the 60-in. telescope, galaxies in Virgo fainter than the ones **Milton Humason** was then studying with the 100-in. nebular spectrograph. Smith's analysis of his, Humason's, and **Vesto Slipher**'s radial velocities of cluster members is the work that brings him into the history of dark matter. He concluded (using nine of his own velocities and about two dozen others) that Virgo had a roughly isotropic distribution of velocities, no significant equipartition of energy, and a mass of 5×10^{14} h^{-1} solar masses (10^{14} at his adopted distance of 2 Mpc). He noted the similarity to Zwicky's result for Coma, and concluded that there must be either large quantities of internebular material or enormous faint extensions beyond the visible galaxies (as just found for M31 bv **Joel Stebbins** and **Albert Whitford** doing photoelectric photometry down to 27 magnitudes per square arc second).

Smith's last years were spent largely on engineering design for the 200-in. telescope, especially its control system.

Virginia Trimble

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Smyth, Charles Piazzi

Born **Naples, (Italy), 3 January 1819**
Died **Ripon, (North Yorkshire), England, 21 February 1900**

Charles Smyth, Astronomer Royal for Scotland between 1845 and 1888, was the first astronomer to argue for the importance of high-altitude observing sites and did pioneering work in solar spectroscopy.

The son of an amateur astronomer and Royal Navy officer, captain **William Smyth** and Annarella (*née* Warrington) Symth, Charles Piazzi's second name honored his godfather, the distinguished Italian astronomer **Giuseppe Piazzi**. After retiring in 1824, W. H. Smyth joined the recently formed Astronomical Society of London (later the Royal Astronomical Society [RAS]), and settled in Bedford, England. There he built the well-equipped Bedford Observatory, where the young Charles learned practical astronomy. After attending the Bedford Grammar School, Charles traveled, at the age of 16, to the Cape Observatory, South Africa, to become assistant to **Thomas Maclear**.

Smyth stayed 10 years at the Cape doing astrometry and participating in an arduous survey of **Nicolas La Caille**'s arc of the meridian, which passed through Cape Town. While in Cape Town, Smyth developed skills in the fledgling process of photography, which fascinated him throughout his life.

In 1844, **Thomas Henderson**, the first Astronomer Royal for Scotland, died in Edinburgh. Smyth's father, then president of the RAS, applied for the position on his son's behalf. When the application was accepted, the younger Smyth arrived in Edinburgh in January 1846, only 27 years old.

Located on Calton Hill, the Royal Observatory, under treasury control, suffered badly from underfunding throughout Smyth's tenure. This did not prevent him from making significant contributions both to astronomy and to Edinburgh. Smyth first reduced and published Henderson's observations. In 1852, he installed a time ball on Calton Hill to signal time for the city and the ships docked at nearby Leith. By 1861, a one o'clock gun fired from Edinburgh Castle, still to be heard daily in the city, augmented Smyth's time ball. In 1855, Smyth married Jessica Duncan, who was scientifically inclined and 4 years older than he.

Smyth was one of the first astronomers to realize the importance of high-altitude observatory sites. The idea that observing could be improved by removing the effects of the lower atmosphere had first occurred to him during his time at the Cape. In 1856, with support from Astronomer Royal **George Airy** as well as the Admiralty, he traveled to Tenerife in the Canary Islands to test his theory. Observing at an altitude of 10,000 ft. Smyth concluded that the high altitude resulted in a gain of about four magnitudes in limiting magnitude compared to that at sea level. By observing double stars, Smyth demonstrated the great improvement in atmospheric seeing at high altitudes. He estimated the heat radiated by the Moon, a pioneering step toward infrared astronomy. It was on the strength of this expedition that Smyth was elected a fellow of the Royal Society in 1857.

Smyth was only one of many distinguished British scientists who debated standardization of units (metrology) during the 19th century. Other leading protagonists included **John Herschel** and **James Maxwell**, both of whom also supported the Imperial System against metrification. Regrettably, Smyth is also frequently remembered for another legacy, his metrology of the Great Pyramid of Giza.

Interest in Egyptology was widespread during the mid-19th century. Smyth's interest ripened into the radical belief that the Great Pyramid was the repository of ancient scientific knowledge. In 1864 and 1865, Smyth went to Egypt, at his own expense, and performed the first meticulous measurements of the Giza Pyramid. The Royal Society of Edinburgh awarded him their biennial Keith Prize and Medal for this work. However, Smyth's developing theories would later garner the distrust of many scientists. The resulting criticism eventually led Smyth to resign from the Royal Society of London, the only person ever to have done so, following the society's refusal to publish papers putting forth his ideas.

Based on astronomical calculations, Smyth concluded that the Great Pyramid was built in 2173 BCE, ignoring contemporary archaeological evidence. He claimed that one of the casing stones of the Great Pyramid revealed an ancient measuring system that resembled the Imperial System, a badly concealed attempt to gain support for the retention of the Imperial System over the metric. Further, Smyth believed that the mathematical structure of the pyramid encoded the events of the Old Testament. This mystical aspect made Smyth the unwitting leader of a worldwide cult movement. The pyramid controversy consumed at least 5 years during what should have been the peak of Smyth's scientific productivity.

Exhausted by the pyramid controversies, Smyth turned his attention again to spectroscopy. With spectrographs of his own design that used the best features of contemporary instruments, Smyth investigated the main features of the solar spectrum during expeditions to Lisbon and Madeira. He used prisms at Lisbon, but a glass diffraction grating ruled by **Lewis Rutherfurd** at Madeira. Using an acetylene flame to calibrate his spectroscope, Smyth measured wavelengths of spectral lines as well as had been done up to his time. For example, his wavelength for the green auroral line was 5579 Å; the modern value is 5577 Å.

An early advocate of the importance of isolating the actual solar spectrum from the combined spectrum of the Sun and terrestrial atmosphere (the telluric spectrum), Smyth observed the Sun close to the morning horizon and again near the zenith at Lisbon. He repeated this work at Madeira, and though conditions were considerably less favorable, quantified all three factors: the actual solar spectrum, the telluric spectrum of dry air, and the effect of added water in a wet atmosphere.

When not on expeditions with his spectroscope, Smyth used his northern latitude in Edinburgh to advantage by studying the light of the aurorae. During the Great Aurora of 4 February 1872, he measured five discrete lines in the auroral spectrum, more lines at more accurate wavelengths than had previously been achieved. On the basis of this work, and work at Madeira and other southern latitudes, Smyth showed that aurorae and the zodiacal light displayed fundamentally different spectra.

An expert in laboratory spectroscopy, Smyth was the first to show that **Joseph von Fraunhofer**'s A and B lines had their origin in the same element, though he guessed wrong in declaring that element was molecular nitrogen. (It is molecular oxygen.) Because of the superiority of his spectroscope and his technique, Smyth was the first to resolve both of these lines and demonstrate the triplet nature of many lines in the oxygen spectrum, a characteristic that eventually led to the correct identification of oxygen in the spectrum of the Sun. Using Smyth's spectral data, **Alexander Herschel** discovered the "harmonic law" in which both strong and weak lines in the spectrum of a molecule follow the same arithmetic progression as their wavelengths grow progressively shorter, a tool of great value to molecular spectroscopists in following generations.

The continued underfunding of the Calton Hill Observatory and Jessica's failing health led Piazzi Smyth to retire in 1888. Disillusioned but resigned to departure from Edinburgh, they moved to Ripon, Yorkshire. In retirement Smyth continued to work, recording the ultraviolet spectrum of the Sun and producing more than 500 photographs of cloud formations, a technique for classifying clouds still widely used by meteorologists.

Smyth lived long enough to see two mountaintop observatories founded, the Lick Observatory on Mount Hamilton, California, and the Arequipa, Peru station of Harvard College Observatory, developments in which he took great satisfaction. In 1890, the University of Edinburgh conferred the degree Doctor of Laws (*honoris causa*) upon Smyth, a great honor for one who succeeded so well without a trace of collegiate education.

Alastair G. Gunn

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Smyth, William Henry

Born **Westminster, (London), England, 21 January 1788**
Died **Aylesbury, Buckinghamshire, England, 9 September 1865**

William Smyth, a leading figure in Britain's golden age of amateur astronomers, published a catalog of celestial objects from his own observing records that served as a stimulus to a generation of new amateur astronomers. He was the son of Joseph Brewer Smyth, an American by birth, and his English wife Caroline (*née* Pilkington). The family's romantic claim that Joseph was descended from the legendary John Smith of Virginia proved to be fiction; Joseph's own story, that as a royalist he lost large estates in New Jersey as a consequence of the American Revolution, was also highly dubious. William ran away to sea at the age of 14 as a cabin boy to avoid poverty at home. His subsequent successful career was therefore remarkable, and entirely the result of his own talents, determination, and cheerful disposition.

After some adventurous years with the navy in the Far East, Smyth saw active service at the siege of Cadiz in 1810 and was promoted for his bravery. Stationed in Palermo after the Napoleonic wars, with the rank of captain in the Mediterranean fleet, Smyth carried out a much-acclaimed hydrographic survey of Sicily, published under the auspices of the Royal Navy. His surveying activities, extending over many years, gave him experience with astronomical instruments. According to Smyth, his interest in astronomy "received its sharpest spur" in 1813 when he met **Giuseppe Piazzi**, director of the observatory of Palermo, and famous as the discoverer of the first minor planet, (1) Ceres, on 1 January 1801. Smyth helped Piazzi with proofreading the sheets of the Palermo star catalog. In 1814, Smyth married Annarella Warington, daughter of the English Consul to the Kingdom of the Two Sicilies, a cultured and artistic woman who shared all his interests and with whom he reared and educated a large family.

In 1821, Smyth was elected to the Astronomical Society of London, which had been founded only the previous year (later the Royal Astronomical Society). In 1824, he retired on half pay from the navy and resolved to devote himself seriously to astronomy. Having lived for some years in London, the family moved to Bedford, about 50 miles from the city. In 1830, Smyth set up his Temple of Urania, a beautifully equipped observatory with an excellent 6-in. Tully refractor, one of the first to be equatorially mounted and driven by clockwork. With this instrument, Smyth embarked on a program of micrometric measurements of double stars drawn mainly from Piazzi's catalog, and observations of nebulae and star clusters. On completion of his survey in 1839, Smyth dismantled the telescope and transferred it to nearby Hartwell House, the mansion of his wealthy neighbor and friend Dr. John Lee, a patron of the arts and sciences, who, under Smyth's guidance, had built his own private observatory.

From 1839 to 1844, Smyth, eventually, elevated to the rank of admiral, was again engaged in naval work, supervising the construction of floating docks in Cardiff. During this time he prepared his catalog of 850 objects, known as the *Bedford Catalogue*, which constituted Part 2 of his popular treatise, *The Cycle of Celestial Objects*, published in 1844. The catalog gained for Smyth the Gold Medal of the Royal Astronomical Society [RAS] in 1845, its highest accolade. The Smyths' home from this time onward was at Saint John's Lodge, Aylesbury, Buckinghamshire, not far from Hartwell House, where Smyth, usually accompanied by his wife, had unlimited access to his beloved equatorial for the rest of his life.

The *Bedford Catalogue*, in which the astronomical data are interspersed with a charming mixture of useful information, historical anecdotes, and classical lore, became one of the most popular works on astronomy in the English language. It gave fresh purpose to amateurs who previously believed that the only way to exercise their hobby was through meridian observations. A true classic, the book has never lost its attraction; a facsimile edition was published in 1986.

One shadow on Smyth's scientific reputation was an allegation made in 1878, long after Smyth's death, by assiduous double star observer Herbert Sadler that Smyth's observations were not original but were copied from earlier compilations. Sadler cited evidence that certain errors in earlier work were repeated in Smyth's catalog. Sadler's accusation, which caused deep offense among Smyth's admirers, had its origin in sarcastic comments published by American double-star observer **Sherburne Burnham**. The handling of the Sadler–Smyth scandal in the RAS Council was inept, leading to adverse comment in scientific journals of the period when Astronomer Royal Sir **George Airy** resigned in protest. The matter was investigated by a respected fellow of the RAS, **Edward Knobel**, who consulted Smyth's original notes, examined his micrometer, and was fortunately able to vindicate him.

Smyth, a devoted member of the RAS, was the society's foreign secretary from 1829 to 1840 and from 1843 to 1845, and president from 1845 to 1847. He was a genial member of the society's dining club, hardly ever missing a dinner and usually taking the chair, while the Smyth home was a hospitable center of scientific social life. Smyth was elected a Fellow of the Royal Society in 1826 and also belonged to the Geographical and Antiquarian Societies.

Lee was not Smyth's only astronomical disciple. Another neighbor, the physician **Thomas Maclear** (later Sir Thomas), under Smyth's inspiration abandoned the medical profession for astronomy, becoming so proficient as to be appointed His Majesty's Astronomer at the Cape, South Africa, in 1831.

Smyth had three sons who all attained eminence in their respective spheres. Sir Warington Wilkinson Smyth was a distinguished geologist. **Charles Piazzi Smyth** became Astronomer Royal for Scotland, while the youngest, Sir Henry Augustus Smyth, was an army general. One of his daughters was the wife of Baden Powell, Oxford mathematician and liberal theologian, and mother of Lord Baden Powell, Boer War hero and founder of the Boy Scout movement. Other sons-in-law were the biologist Sir William Flowers and captain Henry Toynbee, a government meteorologist.

Mary T. Brück

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Snel [Snell], Willebrord

Born **Leiden, (the Netherlands), *circa* 1580**
Died **Leiden, the Netherlands, 30 October 1626**

Willebrord Snel is chiefly remembered for his discovery of the law of refraction that bears his name, and for his demonstration of the first accurate measurement of an arc of the meridian. Snel's father, Rudolph Snellius, was a professor of mathematics at the University of Leiden. There, Snel studied law but remained chiefly interested in science and mathematics. After 1600, he traveled widely in Europe and at Prague met **Tycho Brahe** and **Johannes Kepler**. Snel returned to Leiden in 1604 and began to translate and restore the mathematical works of **Apollonius**. In 1608, he was awarded a master's degree; that same year, he married Maria de Lange. The couple had eighteen children, only three of whom survived to adulthood.

After his father died in 1613, Snel assumed his position at the University of Leiden as teacher and professor of mathematics. He then applied the method of triangulation proposed by **Gemma Frisius** to measure the distance between the towns of Alkmaar and Bergen op Zoom, which lay nearly on the same meridian. For his measurements, Snel used a large quadrant of 2.1-m radius. He presented his results in the booklet, *Eratosthenes batavus* (1617). The method perfected by Snel to discover the Earth's true dimensions was later utilized by French astronomer **Jean Picard** upon a larger meridian arc. Snel, however, apparently remained a follower of the Ptolemaic (geocentric) theory of the Universe.

Snel investigated the refraction of light and succeeded where others (including Kepler) had failed in the derivation of a general law. As it is usually expressed today, the ratio of the sine of the angle of incidence to the sine of the angle of refraction is a constant for a given refractive medium, such as water or glass. Snel arrived at his law of refraction around 1621 but did not publish the finding before his death. Thus, priority for its publication rests with the *Dioptrique* (1637) of **René Descartes**, who had visited with Snel in Leiden. In the words of two later optical scientists, Snel's law "swung open the door to modern applied optics" (Hecht and Zajac, 1974, p. 2).

Jordan D. Marché, II

Alternate name

Snellius

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Snellius

➔ **Snel, [Snell] Willebrord**

Snyder, Hartland

Born **1913**
Died **1962**

With his teacher, **J. Robert Oppenheimer**, American physicist Hartland Snyder showed (1939), using quantum mechanics and general relativity, that a collapsing massive star will continue to collapse until it forms what is now called a black hole.

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Soldner, Johann Georg

Born **near Feuchtwangen, (Bavaria, Germany), 16 July 1776**
Died **13 May 1833**

At Munich, Johann Soldner calculated the deflection, due to gravity, of starlight as it grazes the Sun's limb (1801). Thus he is sometimes said to have presaged **Albert Einstein**; however, because he used Newtonian gravity and a particle theory of light, Soldner's deflection is half of Einstein's 1916 value.

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Somerville, Mary Fairfax Greig

Born **Jedburgh, Scotland, 26 December 1780**
Died **Naples, Italy, 29 November 1872**

Mary Somerville was the first woman scientist to win an international reputation entirely in her own right rather than by working in association with a father, husband, or brother. Self-educated in mathematics and astronomy, she wrote many textbooks dealing with celestial mechanics, geography, and the sciences in general. She was the author of the first paper by a woman ever published in the *Proceedings of the Royal Society* (London).

Mary Somerville was born Mary Fairfax, the daughter of lieutenant, later vice admiral, Sir William George Fairfax. Having seen her husband off on a voyage, her mother, Margaret (*née* Charters) Fairfax gave birth to Mary while traveling from London back to the family home in Fife, Scotland. Given no systematic formal education, Mary was educated by some of her more liberal family members and by her own efforts.

At age 13, Mary was taught painting in Edinburgh by Alexander Nasmyth, father of the engineer, astronomer, and telescope maker, **James Nasmyth**. A chance remark by Alexander Nasmyth that geometry was the basis for understanding perspective as well as the foundation of astronomy set her to the study of mathematics. She studied geometry from Euclid's *Elements*, with the aid of her younger brother's tutor. Her interests broadened to algebra as a result of finding mysterious symbols in the puzzles of a women's magazine, and her brother's tutor provided algebra texts. Her father worried that the strain of abstract thought would injure the tender female frame.

In 1804, when 24 years old, Mary married her distant cousin, captain Samuel Greig. His father was a nephew of Mary's maternal grandfather. A member of the Russian navy, Greig took a post in London in order to marry Mary. Within 2 years the couple had two sons, but he died in 1807. According to Mary, her husband "had a very low opinion of the capacity of my sex, and had neither knowledge of, nor interest in, science of any kind."

With the death of her husband, Mary returned to Scotland as a widow of independent means. She took up mathematics, astronomy, and dynamics, encouraged by the circle of friends whom she had chosen. These included John Playfair (1748–1819), then professor of natural philosophy at Edinburgh, and William Wallace (1768–1843), then professor of mathematics at the Royal Military College. They guided her studies much as a doctoral student would be guided by a professor today.

In 1812, Mary married her second husband, William Somerville, also a distant cousin with naval connections. He was the son of her aunt Martha and her uncle Thomas Somerville. A doctor, William was interested in science and supportive of his wife's interests. Mary and William Somerville moved to London when he was appointed as Inspector to the Army Medical Board in 1816. He was later a physician at the Royal Hospital in Chelsea. When William was elected to the Royal Society, Mary Somerville gained access to a wide circle of prominent scientific acquaintances, including **George Airy**, Humphry Davy (1778–1829), **John Herschel**, **William Herschel**, **Henry Kater**, George Peacock (1791–1858), Thomas Young (1773–1829), and Charles Babbage (1792–1871). She frequently visited Babbage while he was designing his calculating machines. During a visit to Paris in 1817, Somerville met **Jean Biot**, **Dominique Arago**, **Pierre de Laplace**, **Simon Poisson**, Louis Poinsot (1777–1859), Emile Mathieu (1835–1890), and others.

Somerville began experiments on magnetism in 1825. She published her first paper "The Magnetic Properties of the Violet Rays of the Solar Spectrum" in the *Proceedings of the Royal Society* in 1826. Aside from **Caroline Herschel**'s astronomical observations, this was the first paper by a woman to be read at a meeting of and published by the Royal Society. She also wrote about the action of short wavelength radiation on vegetable juices, and about comets.

Somerville began translating Laplace's *Mécanique céleste* in 1827. When the book was published in 1831 under the title *The Mechanism of the Heavens*, it was more than a translation, containing a commentary on the mathematics used, and filling in the gaps in the mathematical development. According to **Nathaniel Bowditch** in a remark since echoed by many a student about many a textbook, "I never come across one of Laplace's 'Thus it plainly appears,' without feeling sure that I have got hours of hard study before me, to fill up the chasm and show how it plainly appears." When Somerville dined with Laplace in Paris in the early 1830s, he paid her a compliment during the conversation. Confused by her name from her earlier marriage, Laplace observed that only two women had ever read the *Mécanique céleste*; both being Scottish women— "Mrs. Greig and yourself."

During her visit to Paris, Somerville wrote her second book, *The Connection of the Physical Sciences,* published in 1834, which treated celestial mechanics and other sciences. The book was published in several editions. In the 1836 edition, she discussed the problematic accuracy of the orbits of the outer planets, suggesting ". . . [T]he discrepancies may reveal the existence, nay, even the mass and orbit, of a body placed forever beyond the sphere of vision." This passage led **John Adams**, by his own admission, to begin calculations in 1843 that led to the discovery of Neptune.

Mary Somerville was elected an honorary member of the Royal Astronomical Society – at the same time as **Caroline Herschel**, the first two women members – in 1835. She was elected to honorary membership of and offered medals by many societies, and awarded a significant civil pension. In 1838, William Somerville's health deteriorated, and the family went to the warmer climate of Italy. There she wrote *Physical Geography*, which was published in 1848 and remained in print for 50 years. Another mark of distinction for that work was that it was admonished from the pulpit in York Cathedral. She published *Molecular and Microscopic Science*, an account of chemistry and physics, in 1869 at the age of 89. William died in 1860. Her daughter Martha published Mary's autobiography in 1873.

Mary Somerville served as an inspired teacher and as a role model for aspiring women scientists. She supported women's education and women's suffrage – hers was the first signature on John Stuart Mill's 1867 petition to parliament for the right of women to vote. Somerville College in Oxford was named in her honor.

Paul Murdin

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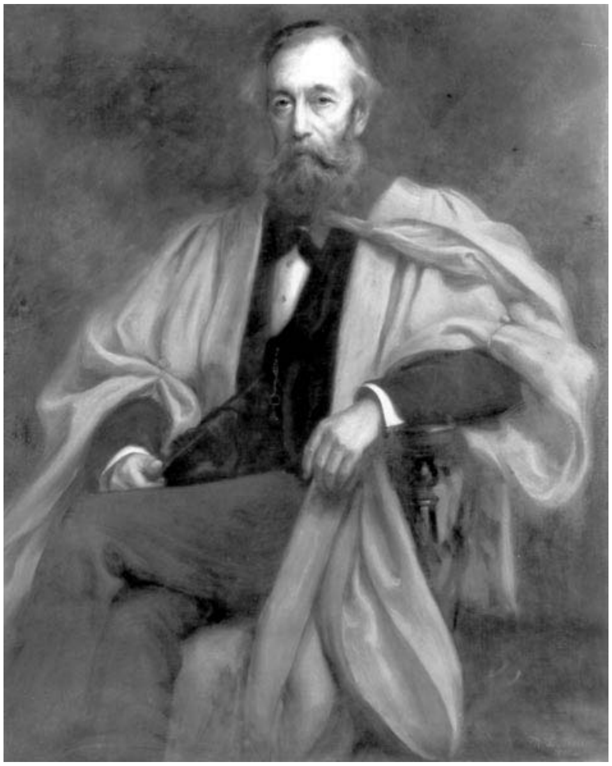
Sorby, Henry Clifton

Born **Sheffield, England, 10 May 1826**
Died **Sheffield, England, 9 March 1908**



Henry Sorby was not a traditional astronomer or a scientist, but a productive amateur scientist particularly interested in meteorites and how they provided evidence concerning the early Solar System. He was the only child of a moderately prosperous family who had a long association with manufacturing edge tools. In 1847, after his father died, Sorby was left with enough income to devote himself full-time to his nearly all-consuming passion, science. Why he did this is not completely clear, but in a speech to the Royal Society in 1874 he noted that

> as a young man, I had to make the choice of either wisdom or riches, and resolved to be content with moderation and devote myself to science, instead of to the accumulation of wealth and trying to rival my richer neighbours (Higham, 1963, p. 8).

Sorby used part of his inheritance to set up a laboratory and workshop at his home. He never married and continued his scientific research until 11 days before his death.

Sorby's link to astronomy comes, ironically enough, from his passion for microscopy. In 1848, Sorby began making thin sections of rocks. In this technique, a thin chip of rock is ground down to a thickness until it can be examined through a microscope by transmitted light. Although Sorby was not the first person to use this technique, he made outstanding contributions to improving it and founded the science of microscopical petrography with a paper in 1851. In this and later papers, he studied the structures of rocks and attempted to understand, usually by experiment, the structural relationships between the different constituents within the rocks and thus to determine how the rocks had formed.

In 1861, the astronomer and meteoriticist Robert Phillips Greg introduced Sorby to the subject of meteors. Greg encouraged Sorby to turn his new investigative methods to the subject of meteorites, which he duly did in 1863. Sorby noted that the thin black crust that surrounded most meteorites was quite often a black glass filled with small bubbles and that there was a sharp boundary between the crust and the main mass of meteorite. This, and other related observations, persuaded Sorby that the crust was igneous in origin and was formed when the meteorite entered the Earth's atmosphere at great speed and was thereby subject to rapid heating, thus confirming a popular theory of the time. Regarding the interiors of meteorites, Sorby noted that some meteorites are similar to brecciated rock; fragments of rock within such meteorites had subsequently been cemented together and consolidated, again confirming a then recently proposed theory.

Sorby was the first to provide an explanation for the formation of chondrules, 0.1 mm silicaceous spheres found in most stony meteorites that are observed landing on the Earth, which may have some connection to the formation of the terrestrial planets. Sorby found a laboratory analog to explain how chondrules were formed. He examined their internal structure and inferred that they were "devitrified globules of glass, exactly similar to some artificial blow-pipe beads" (Sorby, 1877).

Sorby also examined iron meteorites and was particularly interested in understanding the formation of Widmannstätten patterns. He concluded that meteoritic iron formed in a low gravity environment in which the iron was kept at temperatures just below fusion for long periods of time. Such an idea is consistent with the modern understanding for how such metal patterns form.

Sorby concluded, on the basis of the igneous nature of many of the components found in meteorites, that all meteorites were formed near the surface of the Sun and were ejected to the outer regions of the Solar System. Modern observations indicate that most meteorites originate from the asteroid belt, so Sorby's ideas would appear to be completely wrong. Recent work, however, suggests that chondrules and other related igneous objects within meteorites may, indeed, have been formed near the early Sun and ejected to the outer parts of the Solar System by bipolar jet flows, where they aggregate with other material to form the grains in the meteorites that now reach the Earth.

Sorby was one of the first planetary scientists. He used a microscope to study processes that occurred in the distant past during the formation of the Solar System. His methods and conclusions prompted discussions that continue today as we try to understand the processes in young stellar systems and the early history of our Solar System.

Kurt Liffman

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Sosigenes of Alexandria

Flourished **Rome, (Italy), middle of 1st century BCE**

Sosigenes was a Greek or Egyptian astronomer and mathematician of the Alexandrian School, about whom little is known. He is known as the main astronomer who helped Julius Caesar with his reform of the Roman lunar calendar, although his role in this reform is not very clear. **Plutarch** simply states, without mentioning any names, that Caesar consulted the best philosophers and mathematicians before making an improved calendar of his own. And all that **Pliny** says is that during Caesar's dictatorship Sosigenes helped him to bring the years back into conformity with the Sun. He adds that Sosigenes wrote three treatises, including corrections of his own statements. It is, in any case, not certain that Sosigenes was in Alexandria during Caesar's stay in Egypt after the battle of Pharsalos.

Caesar had a genuine interest in astronomy and composed a treatise, *De Astris*, a kind of farmer's almanac with a remarkable popularity, based on Hellenistic data that were made available to him by Sosigenes. Caesar adopted (in 45 BCE) the solar year with an average length of 365¼ days. (The year was to be independent of the Moon's motion; the ordinary year was to consist of 365 days, an extra day being added to February every fourth year.) This may have been one result of Sosigenes' advice, and the statesman's seasonal calendar another. The 365¼-day year even could have been borrowed directly from **Callippus** at the suggestion of Sosigenes. Lucan (*Pharsalia* 10.187) implies that Caesar tried to improve upon the seasonal calendar of **Eudoxus** "and my year shall not be found inferior to the calendar of Eudoxus." T. Mommsen (1887) maintains that Caesar "… with the help of Greek mathematician Sosigenes introduced the Italian farmer's year regulated according to the Egyptian calendar of Eudoxus, as well as a rational system of intercalation, into religious and official use." It is possible, but far from certain, that Sosigenes made use of Babylonian astronomical knowledge.

Little is known about Sosigenes' treatises. It is certain that one of them was based on **Eudemus**' (about 330 BCE) *History of Astronomy.* This work was an intermediary between Eudoxus's and Callippus's systems of concentric spheres, in the account which **Simplicius** gives in his commentary on **Aristotle**'s *De Caelo.* Simplicius's quotation from Sosigenes on the impossibility of reconciling the theory of concentric spheres with the observed differences in the brightness of planets at different times and the apparent difference in the relative sizes of the Sun and Moon is particularly interesting for the history of astronomy. Sosigenes showed that the apparent diameters of the Sun and Moon are not always equal, by describing the phenomenon of annular eclipses of the Sun (on *De caelo*, p. 505. 7–9, Heiberg), and doubtless **Hipparchus** had observed the differences. We also know that Sosigenes agreed with Cidenas in giving the greatest elongation of Mercury from the Sun as 22° (Pliny, *Naturalis historia* 2.39).

Dimitris Dialetis

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South, James

Born **Southwark, (London), England, 21 October 1785**
Died **London, England, 19 October 1867**

James South was a noted amateur astronomer who specialized in binary stars. He is usually remembered for his intemperate disposition, and his infamous quarrel with the instrument-maker Edward Troughton, facts that tarnish the mid-19th-century history of British observational astronomy, and effectively hide the truth of his contributions to scientific knowledge.

South studied surgery, became a member of the Royal College of Surgeons, and built up a thriving practice, but following his marriage to a wealthy heiress in 1816, abandoned medicine for his hobby of astronomy, an interest awakened by his friendship with the hydrographer and surveyor Joseph Huddart. He then proceeded to equip his observatory with the best telescopes and instruments then available. As a result of his friendship with **John Herschel**, with whom he now collaborated, South embarked upon a program of double star observations that lasted from 1821 to 1823, resulting in a catalog of about 380 such stars, which earned Herschel and South the Gold Medal of the recently founded Astronomical Society of London.

South temporarily moved his 5-ft. equatorial to Passy, near Paris, in 1825, where he obtained a series of multiple star measurements of such high quality that the Royal Society, to which he was elected in 1821, awarded him the prestigious Copley Medal (1826). Such was his standing as an astronomer at that time that the British and French governments openly competed to have him and his observatory in their country. He considered imigrating to France, but changed his mind when Britain gave him a knighthood plus £300 per annum to further his researches.

That same year the Royal Astronomical Society, which he had helped to found and had served in a variety of executive positions, gained a royal charter. Unfortunately, a technicality barred him from serving as its first president, a circumstance that prompted his immediate resignation from the society. South was highly critical of the Royal Society, attributing the decline of the sciences in Britain to the actions of some of its members. His attack on the *Nautical Almanac*, which he thought inferior to its Continental counterparts, was equally harsh. Such actions did not endear him to his contemporaries.

South's concern about declining standards culminated in the infamous quarrel with Troughton about the quality of the latter's workmanship. This led to an expensive lawsuit lasting from 1834 to 1838, which South lost. Bitter with rage, he destroyed the offending equipment, and auctioned off the fragments. However, he preserved the lens and toward the close of his life presented it to Dublin University. South was awarded an honorary LL.D. by Cambridge University (1833), and belonged to a number of scientific organizations in Belgium, France, Ireland, Italy, and Scotland.

Richard Baum

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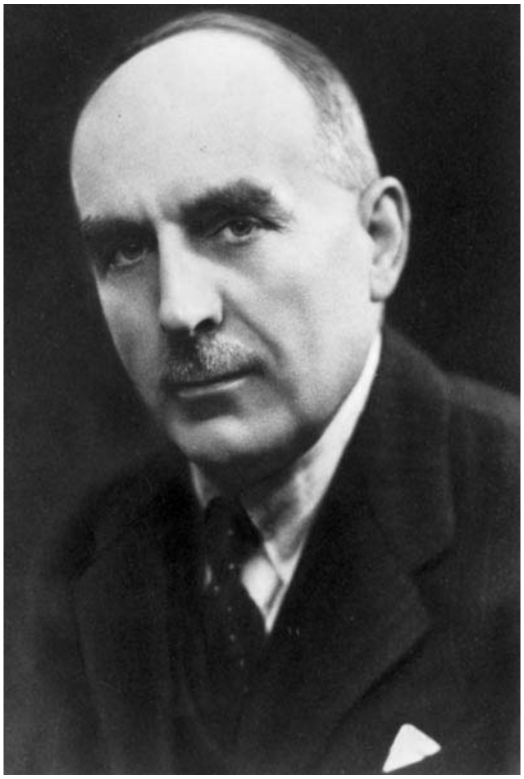
Spencer Jones, Harold

Born **Kensington, (London), England, 29 March 1890**
Died **Herstmonceux, (East Sussex), England, 3 November 1960**



English positional astronomer Sir Harold Spencer Jones compiled the definitive set of data showing that certain apparent irregularities in the motions of the Moon, Sun, and planets actually arise from small variations in the rate of the Earth's rotation; but he made his firmest mark in astronomy as a science administrator. Jones was the third child of Henry Charles Jones, an accountant, and was educated at Latymer Upper School, Hammersmith and Jesus College, Cambridge, where he received first class honors degrees in mathematics (1911) and natural science (1913). Spencer Jones was elected to a fellowship at Jesus College in 1913, but the next year was appointed as one of the chief assistants at the Royal Greenwhich Observatory [RGO] by its director, Astronomer Royal **Frank Dyson**, replacing **Arthur Eddington**, who had just been elected to the Plumian Professorship at Cambridge. Spencer Jones's first task there was participation in an expedition to observe the solar eclipse of 21 August 1914 from Minsk, Russia. During World War I, he served as an inspector of optical supplies for the Ministry of Munitions. Spencer Jones married Gladys Mary Owens in 1918, and they had two children.

In 1923, Spencer Jones was appointed His Majesty's Astronomer at the Cape of Good Hope, South Africa. On his arrival, he found an inefficient staff and numerous observational programs dating back decades whose results were still awaiting reduction. Spencer Jones proceeded to reenergize the observatory, superintending a new edition of the Cape Catalog of southern stars, a reobservation of the Cape zone of the Astrographic Catalogue (*Carte du Ciel*) for measurements of proper motions, and, most important, analysis of measurements of lunar occultations from 1800 to 1922 and positional observations of Sun, Mercury, Venus, and Mars dating from 1836 to 1924. These data provided firm evidence that the rotation rate of the Earth varies on time scales from days to decades, at least, and that these variations must be taken into account when determining precise orbital motions for the Moon and planets.

The International Astronomical Union elected Spencer Jones president of its Commission on Solar Parallax in 1928, and he was, therefore, the coordinator of a 24-observatory campaign during 1930/1931 to track the opposition of Eros, which passed unusually close to Earth that winter, in the hopes of improving knowledge of the distance scale within the Solar System *via* the phenomenon of geocentric or Earth-rotation parallax. The published result (π = 8.7904 arc sec) yielded Gold Medals for Spencer Jones from both the Royal Astronomical Society and the Royal Society (London), though later work showed it was not so accurate as he had supposed, despite the 2,847 plates collected for the program (many of which were measured by **Philibert Melotte**).

Spencer Jones was recalled to England in 1933 to become the 10th Astronomer Royal and director of the Royal Observatory at Greenwich, just outside London. Again he implemented notable upgrades, bringing into operation the 36-in. Yapp telescope and the Cooke reversible transit circle (which replaced an instrument commissioned in 1850 by **George Airy**) and cooperating with the post office to provide "speaking clock" time service for England. Spencer Jones soon also recognized the decreasing suitability of the Greenwich site, close to the lights of London and embedded in Thames River fogs. Early considerations of relocation were interrupted by World War II, during which most of the Greenwich instruments were dismantled for safe storage, so that rather little astronomy, even of the conventional, positional sort, could be done there during the war or afterward.

The postwar English astronomical community was badly divided over what to do next; many (especially those engaged in imaging of distant objects) favored development of a site outside England, where the air would be clearer and drier much of the year. Several factors, however, militated in favor of Spencer Jones's preference for remaining in England. One was the unexpected availability of many country locations, as suddenly impoverished aristocrats sought to sell their homes or donate them to the government. Another was the immediate availability of a 98-in. Pyrex mirror blank (originally a trial cast for the 200-in.), acquired by the University of Michigan but never incorporated into a telescope. Herstmonceux Castle was adjudged the most suitable of the domestic sites, and Spencer Jones moved his office there in 1948. Even the existing operations were not fully transferred until after his 1955 retirement, and the 98-in. Isaac Newton telescope became operational only in the late 1960s. The observatory retained the Greenwich name, though its administrative offices were relocated again (to Cambridge) and eventually closed, while portions of the 98-in. were moved to the Canary Islands.

Spencer Jones was very much a public man. He was the only individual to hold all four of the major elective offices in the Royal Astronomical Society until Sir **William McCrea**. He was appointed president of the International Astronomical Union in 1944 by the subset of its officers who were in communication at that time, when Eddington, who had been elected in 1938, died; served as secretary general of the International Council of Scientific Unions (1955–1958); participated in the deliberations that made science part of United Nations Educational, Scientific, and Cultural Organization [UNESCO]; and was knighted for his services to the country. Spencer Jones received some 11 honorary doctorates and was elected to memberships in a comparable number of academies of science. Part of his influence appears to have been attributable to a commanding physical presence and the ability to draft coherent, persuasive arguments orally or on paper very quickly. Curiously, just as one of Dyson's early actions as director of the Royal Observatory had been to appoint Spencer Jones, who became his successor, one of Spencer Jones's first actions in 1933 was the appointment, as a chief assistant, of **Richard van der Riet Wooley** who, in turn, succeeded him as Astronomer Royal and director of the RGO (the last person for whom the two jobs automatically went together).

The official papers of Spencer Jones are in the archives of the RGO at the Cambridge University Library.

Keith Snedegar

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Sphujidhvaja

Flourished **(India), third century**

Sphujidhvaja's *Yavanajātaka*, a poetic version of **Yavaneśvara**'s *circa* 150 work translated from the Greek, is the best surviving evidence for transmission of Hellenistic astronomy to India.

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Spitz, Armand Neustadter

Born **Philadelphia, Pennsylvania, USA, 7 July 1904**
Died **Fairfax, Virginia, USA, 14 April 1971**

Planetarium entrepreneur Armand Spitz contributed to the design of planetariums that could bring the sky to the public at low cost. The son of Louis and Rose (*née* Neustadter) Spitz, he was raised in the Quaker faith and maintained an affiliation with the Newtown Square, Pennsylvania, Friends Meeting throughout his life. Spitz graduated from West Philadelphia High School in 1922. He first matriculated at the University of Pennsylvania; two years later, he transferred to the University of Cincinnati, but left to pursue a career in journalism without receiving his degree. In 1928, Spitz became editor and later publisher of the Haverford *Township News*. The great economic depression, however, forced the venture into bankruptcy. Spitz's former colleague on the newspaper, Vera Golden, edited the revitalized *Township News*. Spitz and Golden later married and had two children, a daughter Verne and son Armand.

Spitz volunteered for work at Philadelphia's Franklin Institute and was eventually employed there. He prepared newspaper publicity and edited the institute's newsletter (1936–1943). By successively capitalizing on his resources as he gained experience and knowledge, Spitz acquired a host of duties at the institute, eventually becoming head of museum education. Spitz organized the institute's department of meteorology and taught courses in that subject. He was cofounder of the Amateur Weathermen of America (1946) and of the journal, *Weatherwise* (1948), later published by the American Meteorological Society. Spitz authored two texts in meteorology, a detailed history of American meteorology, and served as Philadelphia's first television weatherman.

However, Spitz's interest in astronomy was even greater than his interest in meteorology. He was excited by the presentations of **James Stokley** and other lecturers at the Fels Planetarium of the Franklin Institute. These performances fueled Spitz's desire to become a lecturer himself, but for years he was denied this opportunity because he lacked a college degree. Spitz's growing passion for astronomy was first channeled into the construction of a Springfield-mounted reflecting telescope and 3-ft. diameter replica of the Moon. He worked out an affiliation with the astronomy department of Haverford College, and gained the use of the 10-in. Clark refracting telescope in their Strawbridge Observatory to observe double stars.

Spitz's first book, *The Pinpoint Planetarium* (1940), was an important stepping-stone toward the creation of an inexpensive pinhole-style planetarium projector. Consultation with mathematical authorities, including **Albert Einstein** of Princeton, New Jersey, convinced Spitz that a twelve-sided dodecahedron could be used to project realistic images of the sky onto an artificial dome. With financial support and mechanical expertise provided by several of his meteorology students, Spitz unveiled his prototype projector in 1945. The sky portrayed by the Spitz Model A projector included roughly 1,000 stars. Although unable to match the sophistication of a Zeiss instrument costing several tens of thousands of dollars more, Spitz's Model A projector nonetheless offered a realistic display of the stars and planets visible to the unaided eye. The initial cost of the device was only $500.

Spitz joined with David M. Ludlum (born: 1910), who sold meteorological equipment, to found Science Associates in 1946. The firm marketed, among other products, the Spitz Model A planetarium projector. An important demonstration of the Model A projector occurred in 1947 when *Sky & Telescope* editor **Charles Federer** arranged for Spitz to present a planetarium program to a joint meeting of the Bond Astronomy Club and the American Association of Variable Star Observers [AAVSO], using a production version of the Model A. That meeting, which took place in Cambridge, Massachusetts, provided the first substantial publicity for the venture.

In the following years, the portability of the Model A allowed it to be taken to many similar meetings where demonstrations established the credibility of the pinhole-style projector. Spitz Laboratories was incorporated in 1949, although its products were marketed by Science Associates through 1951. Thereafter, Spitz resigned his duties at the Franklin Institute to devote full attention to the sale and installation of planetarium projectors. By the end of 1953, Spitz had sold his 100th projector; many went to institutions outside the United States. He relocated his company several times before its last facility was established at Chadds Ford, Pennsylvania, in 1969. By then, as noted by Brent P. Abbatantuono, Spitz's pinhole-style projectors had "revolutionized the availability of artificial skies."

In 1956, Spitz was chosen as national coordinator of visual satellite observations for Project Moonwatch, a program developed by the Smithsonian Astrophysical Observatory. Project Moonwatch organized a corps of amateur astronomers and others to track the first artificial satellites launched during the International Geophysical Year [IGY]. As a measure of Spitz's success, at least seventy nine stations in the United States, staffed by more than 1,200 individuals, were officially registered by the start of the IGY. Dozens of other Moonwatch groups were established around the world, especially in Japan.

Spitz was awarded an honorary D.Sc. degree in 1956 by Otterbein College at Westerville, Ohio. He gained further recognition that same year when he was named a special consultant to the National Science Foundation, serving in that capacity until 1960. He utilized the prestige associated with that position to help professionalize the American planetarium community, organizing nationwide symposia held at Bloomfield Hills, Michigan (1958), and Cleveland, Ohio (1960). Out of these symposia, the first monographs on planetarium education were produced. The IGY and post-Sputnik era caused substantial turmoil in Spitz's personal life, however. In 1957, he and Vera were divorced; in 1958 he married medical statistician Grace

C. Scholz (born: 1912). Scholz had previously served as executive secretary and president of the Astronomical League, the nation's largest association of amateur astronomers.

Federal assistance arising from passage of the National Defense Education Act of 1958 triggered a third and larger phase of American planetarium growth. But Spitz himself no longer played a significant role in this development. He retired from the company in 1961, though remaining active in the planetarium community for several more years. In 1951, Spitz had organized an association of planetarium directors, under the auspices of the American Association of Museums [AAM]. He attempted to improve the association's communications by creating a newsletter, named *The Pointer*, which was edited by Hayden Planetarium chairman Robert R. Coles (1952/1953). *The Pointer*'s significance lay in its being the first regular publication to originate within the American planetarium community. The AAM's "planetariums section" met on a yearly basis through the 1960s. Continued growth of planetariums made possible the formation of newer regional associations, and in 1970 the larger International Society of Planetarium Educators was founded. Were it not for Spitz's invention of the pinhole-style planetarium projector, such an association might never have come into existence.

In 1966, Spitz suffered a stroke that left him partially paralyzed. An annual lecture series, named in Spitz's honor, was established in 1967 by the Great Lakes Planetarium Association.

Jordan D. Marché, II

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Spitzer, Lyman, Jr.

Born **Toledo, Ohio, USA, 26 June 1914**
Died **Princeton, New Jersey, USA, 31 March 1997**

American astrophysicist Lyman Spitzer, Jr. made major contributions to our understanding of diffuse gases, especially the interstellar medium, and was among the first to strongly urge the construction of a large optical telescope in space. He was the son of Blanche C. and Lyman Spitzer, and married Doreen Canaday in 1940.

Lyman Spitzer was educated at Phillips Academy (Andover), Yale University (BA: 1935), Cambridge University (where he attended informal lectures by **Subrahmanyan Chandrasekhar** at Trinity College), and Princeton University, where he earned a Ph.D. in 1938 for work with **Henry Norris Russell** on the analysis of spectra of cool supergiant stars. Spitzer held a National Research Council Fellowship at Harvard (1938/1939), where **Harlow Shapley**, **Donald Menzel**, **Bart Bok**, and **Martin Schwarzschild** were particularly influential. He was an instructor at Yale (1939–1942), before moving to war work (1942–1946) at Columbia University, where he became the director of the sonar analysis group before returning to Yale (1946–1947). In 1947, Spitzer became director of the observatory and chair of the astronomy department at Princeton (positions he held until 1979), as successor to Russell, where one of his first actions was to persuade Martin Schwarzschild to join the Princeton group. They remained close colleagues for 50 years thereafter.

Spitzer's scientific contributions fall into a number of fairly district areas – physics of the interstellar medium; stellar dynamics; laboratory plasma physics and controlled thermonuclear fusion; and space astronomy and astrophysics.

Spitzer's career spanned the period from before the recognition of a general interstellar medium to the time when half a dozen different phases of interstellar material had been characterized, and his monograph *Physical Processes in the Interstellar Medium* served as the standard for two decades. He computed the mean free paths of electrons, ions, atoms, and dust grains, showing that the various phases tended toward pressure equilibrium, and thereby predicted a hot, "coronal" medium outside the galactic plane, later found. He was among the first to conclude that star formation must be an ongoing process, in a paper written before World War II. (It was trimmed of the star-formation section for later publication, but restored to the original text in the reprint volume of his papers.) He also pointed out the importance of magnetic fields and dust in star formation.

In the realm of stellar dynamics, Spitzer, concurrently with **Viktor Ambartsumian**, calculated the rate at which stellar encounters in clusters eject stars, introduced several new ideas into the study of dense star clusters, urged a Princeton student (Haldan Cohn) to develop numerical methods for simulating cluster evolution, and wrote another definitive monograph, *Dynamical Evolution of Globular Clusters*. Seven additional Spitzer students at Princeton were eventually also involved in cluster work. Spitzer and Martin Schwarzschild together suggested that the gravitational influence of giant gas clouds was responsible for the gradually increasing velocities of stars in the galactic plane as they age, and Spitzer went on to show that gravitational impulses from such clouds were also responsible for the dissolution of most star clusters before they reach an age of 100 million years. He and **Walter Baade** also introduced the idea of gravitational interaction between galaxies.

Spitzer was involved in the Princeton-controlled thermonuclear fusion program from its inception as Project Matterhorn (1953–1961) and through the early years of the Princeton Applied Physics Laboratory (1961–1967). His design, called the "stellerator," for a magnetically confined plasma, had obvious astronomical roots and a formal basis in lectures given at Princeton by visitor **Thomas Cowling**.

Some kinds of astronomy can be done only from above the Earth's atmosphere, and some phenomena are best studied *in situ*. Even before the war, while at Yale, Spitzer had tried to organize a program in solar ultraviolet spectroscopy and to recruit **Leo Goldberg** into it. The ultraviolet Copernicus satellite, launched in 1972, was the eventual fruit of this interest, and the spectrometer designed by his group discovered interstellar molecular hydrogen, measured the ratio of deuterium to normal hydrogen in interstellar gas, and found highly ionized atoms as evidence of the million-degree coronal component he had predicted long ago. Spitzer began urging the construction of a 3-m class telescope in space as early as 1947. He shepherded through National Aeronautics and Space Administration planning, and congressional scrutiny of what is now known as the Hubble space telescope [HST]. For many years, he chaired the Space Telescope Institute Council, the oversight group for the institute that selects observing programs and processes data for the HST. He had also urged Martin Schwarzschild to develop the Stratoscope Balloon program for high-resolution astronomy, with input as well from **James Van Allen**, whom Spitzer temporarily attracted to Princeton for the Plasma Lab. Spitzer was awarded six honorary doctorates and medals and awards from the Royal Society (London), the Royal Swedish Academy of Science, the American Astronomical Society (which he served as president during 1960–1962), the Royal Astronomical Society, and several others. He was elected to membership in the United States National Academy of Sciences, the Royal Society of Science of Liège, the American Academy of Arts and Sciences, and other both honorary and scientific service organizations.

In addition to writing many scientific papers in various astrophysical journals, Spitzer wrote important textbooks, which are useful to researchers and graduate students because they include new results from his studies.

Satoru Ikeuchi

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Spörer, Friedrich Wilhelm Gustav

Born **Berlin, (Germany), 23 October 1822**
Died **Giessen, (Hessen), Germany, 7 July 1895**

Friedrich Spörer is best known for his refinement of our understanding of sunspots. He is commemorated in the name of the Spörer minimum, an absence of sunspots *circa* 1450.

Spörer was the son of a German merchant. He studied at the University of Berlin, where his most influential teachers were Heinrich Wilhelm Dove (1803–1873) and **Johann Encke**. His thesis on the 1723 comet (C/1723 T1) earned him a doctorate in 1843, after which Spörer worked as a "computer" for Encke, responsible for the calculation of cometary orbits.

Spörer left the Berlin Observatory in 1846 to pursue a career as a teacher. He taught mathematics and natural sciences in various Gymnasium and Grammar Schools, first in Bromberg, then in Prenzlau, and finally in Anclam, where he remained for 25 years and eventually became prorector.

Spörer's main contribution to astronomy remains his extensive studies of sunspots and their cycles, which he carried out as an avocational pursuit for many years while teaching. Starting in 1860 and working with a small and inferior telescope, he embarked on a sustained sunspot observing program aimed at determining the rotational elements of the Sun with better accuracy. His first task was to recompute the inclination of the Sun's axis with respect to the ecliptic, and the longitude of its ascending node. Spörer then studied the apparent rotational motion of sunspots, rediscovering the solar latitudinal differential rotation found by British astronomer **Richard Carrington**. He also investigated in great detail what he dubbed the "law of zones" At any given time in the cycle, sunspots are confined to two relatively narrow latitudinal bands on either side of the solar equator, and these bands gradually migrate equatorward in the course of the cycle. Although this behavior had been noted earlier by Carrington, Spörer studied it so assiduously that the phenomenon came to bear his name. Spörer also observed that successive cycles overlap slightly, in that the high-latitude sunspot bands associated with a new cycle appear while sunspots from the preceding cycle are still seen close to the Equator. Finally, he noted the common lack of symmetry between the number of sunspots observed in the Northern and Southern Solar Hemispheres.

The high quality of the observations Spörer carried out during his free time throughout those years attracted the attention of the tutor to Crown Prince Frederick Wilhelm (later Kaiser Frederick II). An immediate practical consequence for Spörer was the 1868 gift by the Crown Prince of a larger, high-quality telescope with which to pursue his sunspot research. Another apparent consequence of the recognition Spörer finally achieved also occurred in 1868, when he was invited to participate in the German eclipse expedition to the East Indies, which was unfortunately plagued by bad weather on eclipse day.

Recognition of Spörer's scientific effort eventually led, in 1874, to his appointment at Potsdam Observatory, then in the planning stage, where he became chief observer in 1882. Spörer subsequently engaged in historical researches aimed at examining whether his "law of zones" held in prior sunspot cycles. It is in the course of these investigations that he noted the striking dearth of sunspots between 1645 and 1715, as well as the pronounced North–South asymmetry in the few sunspots that were observed at the time. Surprisingly, these findings attracted relatively little attention at the time, and this curious break in the sunspot cycle is now known as the Maunder minimum, even though the British astronomer **Edward Maunder** clearly and vigorously publicized the historical sunspot researches as Spörer's work. An earlier period of reduced activity is called the Spörer minimum.

In 1885, Spörer was awarded the Valz Prize of the Institut de France. He was also elected a foreign associate of the Royal Astronomical Society in 1886, and a corresponding associate of the Società degli Spettroscopisti in Italy in 1889. Spörer retired from Potsdam Observatory on 1 October 1894. Having enjoyed perfect health throughout his life, he died suddenly of a heart attack, while on a trip to visit his children.

Paul Charbonneau

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Śrīpati

Flourished **Rohinīkhanda, (Mahārāṣṭra, India), 1039–1056**

Śrīpati was an Indian (Hindu) astronomer. His father was Nāgadeva, and his grandfather was **Keśava** of the Kāśyapagotra. Śrīpati composed three astronomical works; the *Siddhāntaśekhara*, the *Dhīkoṭidakaraṇa* (1039), and the *Dhruvamānasa* (1056); a mathematical work, the *Gaṇitatilaka*; and two astrological works, the *Jātakapaddhati* (or *Śrīpatipaddhati*) and the *Jyotiṣaratnamālā*. Śrīpati is the only other astronomer, after **Varāhamihira** and **Lalla**, whose works spanned both astronomy and astrology. All other astronomers wrote exclusively on mathematical astronomy as far as extant texts are concerned.

Śrīpati's *Siddhāntaśekhara* followed the Brāhma School of **Brahmagupta**, one of four principal schools of astronomy active in the classical period (late 5th to 12th centuries). The Ś*iddhāntaśekhara* is a treatise on mathematical astronomy and consists of 19 chapters.

At the same time, Śrīpati was much influenced by the *Śiṣyadhīvṛddhidatantra* of Lalla, a follower of the Ārya School of **Āryabhaṭa I**. Śrīpati's *Jyotiṣaratnamālā* followed the *Jyotiṣaratnakośa* of Lalla.

The *Dhīkoṭidakaraṇa* is a work of 20 verses that gives methods of calculation for lunar and solar eclipses. The *Dhruvamānasa* is, according to D. Pingree, a work of some 105 verses used for calculating a variety of lunar and planetary phenomena.

Among Śrīpati's two astrological works, the *Jātakapaddhati* is a textbook on horoscopy, while the *Jyotiṣaratnamālā* is an influential work on catarchic astrology. It contains Śrīpati's own commentary (written in Marāthī).

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Ssu-ma ch'ien

➔ **Sima, Qian**

Stabius, Johann

Flourished ***circa* 1500**

Johann Stabius was court astronomer to Maximilian I in Vienna. **Albrecht Dürer**'s famous celestial charts illustrate Stabius's 1515 atlas. The star positions were provided by Conrad Heinfogel.

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Stark, Johannes

Born **Schichenhof, Bavaria, Germany, 15 April 1874**
Died **Traunstein, Bavaria, (Germany), 21 June 1957**

German experimental physicist Johannes Stark is important within astronomy for the Stark effect, the broadening or splitting of atomic emission and absorption lines when the atoms producing them are in an ambient electric field, such as that due to the surrounding ions and electrons in the atmosphere of a star.

Stark was born to a landed proprietor and his wife. Stark's early life included an education at the Gymnasium in Bayreuth and later in Regensburg. Upon graduation, he enrolled at Munich University in 1894 to study physics, mathematics, chemistry, and crystallography. Stark completed his doctorate in 1897 with a dissertation on **Isaac Newton**'s electrochronic rings in dim media. Upon completion of his doctorate, he worked as an assistant at the Physics Institute at Munich University, a post Stark held until 1900, when he became an unsalaried lecturer in physics at the University of Göttingen. In 1906, he moved on to a professorship at the Technische Hochschule in Hanover until 1909, when he switched to the Technische Hochschule in Aachen.

During this period, Stark studied the behavior of "canal rays" (rapidly moving positively charged particles, so called because they come out of an opening or canal in a cathode) in hydrogen gas, some of the results being published in journals of astronomy. In 1910, he was awarded the Baumgartner Prize of the Vienna Academy of Science, and he received the Rome Academy's Matteucci Medal in 1914.

In 1913, Stark showed that, when a strong electric field is applied to hot, glowing hydrogen gas, the Balmer lines split into a number of components. In the stellar context, one can think of such a field as being produced, on average, by the large number of ions and electrons around the atoms that are emitting or absorbing the lines. The effect is to broaden the Balmer and other lines, making them look stronger, rather than to split them into several separate lines. Stark's 1919 Nobel Prize in Physics was awarded both for the line-splitting discovery and for his work on canal rays.

In 1917, Stark moved to a professorship at the University of Griefswald and on to the University of Wurzburg in 1920. Beginning in the early 1920s, Stark, together with Philipp Lenard and Ernst Gehrcke, attempted to oppose the spread of nonclassical physics, both general relativity and quantum mechanics, within Germany. By the 1930s, part of the reason for their opposition was that much of the nonclassical work had been done by Jewish scientists, and the Nazi party came to support their campaign for "Aryan physics" (including, *e. g.*, the republication of a **Johann Soldner** paper from the early 1800s that derived gravitational bending of light from Newtonian mechanics and a particle theory of light). This support probably contributed to Stark's 1933 election as president of the Physikalisch-Technische Reichsanstalt (Physico-Technical Institute). The German physical community came to oppose the strange scientific ideas of Stark and Lenard by about 1940, and in 1939 Stark retired to a private laboratory, set up with money from his Nobel Prize, where he died. He was married to Luise Uepler, and they had five children.

Modern calculations of Stark broadening distinguish a linear Stark effect (due to other atoms of the same element) and a quadratic Stark effect (due to atoms of other elements and electrons). All of atomic physics rests on a foundation of quantum mechanics, ironical in the light of Stark's opposition to it, though in the case of his effect, the quantum mechanical aspect can be described by a single parameter, and the calculations of the average electric fields at a given location can be done classically.

Ian T. Durham

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Steavenson, William Herbert

Born **Quenington, Gloucestershire, England, 26 April 1894**
Died **South Marston, Wiltshire, England, 23 September 1975**

William Steavenson was renowned for his observational skills and knowledge of instruments. Steavenson was the youngest child of Reverend Frederick Robert Steavenson, rector of Quenington, Gloucestershire.

Steavenson came to astronomy early, and on 25 December 1917, he noted in one of his observation diaries that it was "the tenth anniversary of my astronomical birthday." This signified the occasion in 1907 when, having viewed the Moon through a 1.75-in. aperture telescope, Steavenson suddenly appreciated the potential of even a modest telescope. Soon after he was given an equatorially mounted 3-in. refractor on a wooden tripod, and began serious observation of the Moon, the planets (especially Jupiter, Saturn, and their satellites), and whatever comets and novae he could access.

By 1910, Steavenson had entered into published correspondence with long-standing contributors to *The English Mechanic* on such wide-ranging topics as the possible light variation of Hyperion, a suspected tiny crater on the wall of the lunar crater Aristarchus, and the detail visible on Saturn in good seeing. In March 1912, Steavenson was writing about Nova Geminorum, and reporting on the trail of a meteor he had registered while photographing the region of the nova.

Steavenson first made headlines in September 1911 when he took a series of comet photographs. This activity by a schoolboy excited wide interest and brought Steavenson to the attention of the Astronomer Royal, **Frank Dyson**, then president of the Royal Astronomical Society. He immediately proposed the youngster for a fellowship of the Society, and on 12 January 1912 Steavenson was duly elected. This in the words of his obituarist brought him more publicity and marked him "as a very active and persevering amateur astronomer." By December 1914, Steavenson had also joined the Society for Practical Astronomy [SPA] in the United States and less than a year later was appointed director of the SPA Comet Section.

Following the severe illness of his father, the family took up residence at Cheltenham, Glouchestershire, and William Steavenson entered Cheltenham College, starting in the preparatory school. Here he won a classical scholarship. He received his medical training at Guy's hospital, London.

In 1916, while still a medical student, Steavenson conducted an experiment to determine, photographically, the diameter of the fully dark-adapted pupil of a normal eye. His finding of more than 8-mm was in sharp contrast to the 5-mm standard assumption on which optical designs were then based, and was adopted for use in optical design thereafter.

Steavenson served as a civil surgeon in a military hospital at Millbank, London, during 1918 and 1919. In 1919, he was appointed a captain in the Royal Army Medical Corps, and spent 6 months in Egypt, but resigned his commission in 1920. With his mother and sister, Steavenson eventually settled in West Norwood, a suburb of London, and set up an observatory there.

In 1923, in company with Reverend **Theodore Phillips**, he edited *The Splendour of the Heavens*, a large multiauthor compendium of astronomical knowledge that proved spectacularly popular with amateurs and professionals alike, and is now a classic of its kind. In 1927, Steavenson visited observatories in North America for his own edification, and in mid-1929 he was asked to travel to South Africa, where he spent 6 months investigating seeing conditions at the possible site for the new Radcliffe Observatory.

Soon after Steavenson returned from South Africa in 1930, a 20-in. reflector replaced the 6-in. Wray refractor set up in 1922 at West Norwood. Few fine nights were wasted, and his log abounds with observations of novae, comets, planets, and the satellites of Uranus.

In 1939, the growing menace of light pollution in the metropolis caused Steavenson to move to Cambridge. He felt a larger instrument would be wasted near London. **Arthur Eddington**, then director of the University Observatory at Cambridge, gave him permission to install a 30-in. Hindle reflector and dome on the observatory grounds. By the summer of 1939, the dome was built and the new telescope installed. However, with the outbreak of hostilities in September, Steavenson went to help medical friends with their practice in Cheltenham, and the observatory remained closed until the summer of 1945 when he returned to The Hermitage, Newnham, Cambridge (later to become Darwin College).

Steavenson resumed work on 10 August 1945 and continued with unabated vigor for the next 10 years. With the greater light grasp available, Steavenson renewed his photometric studies of the satellites of Uranus, now including position measures with a home-made position-micrometer.

In 1956, Steavenson decided to abandon observing. No one knows why. Perhaps the process was becoming too strenuous; more likely it was putting his surviving eye under strain. (He had lost the right eye in a boyhood accident.) Whatever the reason, his telescope was given to the Cape Observatory and, at the age of 62, Steavenson returned to Cheltenham in the Cotswold country of his origin. Finally in 1971 he went to live with a niece at South Marston, Wiltshire, who looked after him for the last 4 years of his life.

Steavenson was elected a member of the British Astronomical Association on 28 May 1913. He served as acting director of the Saturn Section from 1917 to 1919, director of the Mars Section from 1922 to 1930, and director of the Instruments and Observing Methods Section from 1932 to 1961, a position for which he was ideally suited. Many astronomers, professional and amateur, had cause to remember his inspiring advice with gratitude. Recognition of his outstanding abilities as an observer first came when Steavenson was elected president of the British Astronomical Association for the period 1926–1928. In 1928, he was awarded the Jackson-Gwilt Medal of the Royal Astronomical Society, and in 1961 the prestigious Walter Goodacre Medal of the British Astronomical Association. His greatest honor however, was to be elected president of the Royal Astronomical Society for the period 1957–1959. Steavenson was also Gresham Professor of Astronomy from 1946 to 1964, and astronomical correspondent of *The Times* from 1938 to 1964.

Richard Baum

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Stebbins, Joel

Born **Omaha, Nebraska, USA, 20 July 1878**
Died **Palo Alto, California, USA, 16 March 1966**

American photometrist Joel Stebbins was an innovator in the use of photoelectric photometry, and in 1915 applied these techniques to measure the first light curve of an eclipsing binary from which the distance to the system could be determined. He also used photoelectric photometry to make the first quantitative measurement of night-sky brightness caused by urban light pollution and to look for evidence that galaxies had changed their colors with the evolution of the Universe.

The son of Charles Sumner and Sara Ann (*née* Stubbs) Stebbins, Joel developed an early interest in astronomy. His first jobs (apart from newspaper delivery boy) included part-time surveying work for the Union Pacific Railroad, which employed his father. His marriage in 1905 produced two children, but the family member to whom he was closest seems to have been his sister Millicent, who sometimes made Wisconsin–California summer round trips with him.

Stebbins obtained a B.S. degree from the University of Nebraska in 1899 – he was awarded an honorary LL.D. in 1940 – and continued as a student at University of Wisconsin (1900/1901), before completing a Ph.D. in astronomy (spectroscopy) at the University of California, Berkeley (1903), the third such degree awarded by the department. (Wisconsin awarded him an honorary D.Sc. in 1920.) Stebbins joined the faculty at the University of Illinois first as an instructor in astronomy (1903/1904) and subsequently as assistant professor (1904–1913). After a sabbatical at the University of Munich (1912/1913), he returned as professor and director of the Illinois observatory (1913–1922). Stebbins moved to the Illinois of Wisconsin as professor and director of the Washburn Observatory in 1922, holding that position until his retirement in 1948. From 1922 to 1948, Stebbins also was a research associate at Mount Wilson. Following his retirement, on termination of the Mount Wilson research associate program, Stebbins remained affiliated with the Lick Observatory until his death.

Stebbins' work was in the precision photometric measurement of cosmic objects, and he was a pioneer of, and propagandist for, photoelectric photometry throughout the first half of the 20th century. At the time the basic limitations of accuracy and dynamic range precluded observations of faint stars and rapidly varying sources using visual and photographic photometry.

A selenium cell, which functioned as a variable resistor in a Wheatstone bridge with a galvanometer as a detector, was limited by the stability of the power supply and the sensitivity of the galvanometer. Stebbins provided the first astronomical calibrations on a selenium cell in 1908, showing that the peak response was at about 7,000 Å with a range of about 2,000 Å (to a sensitivity of about 25% of peak). The detector was, though, nearly blue and ultraviolet blind, rendering it a poor choice for photometry of nearly all stars hotter than the Sun. For this work, a new detector was required and again Stebbins was at the forefront of the search.

Stebbins attributed his inspiration for using photoelectric detectors for astronomical photometry to a 1906 lecture by his colleague F. C. Brown. The technique was similar to that of Philip Lenard (codiscoverer of the photoelectric effect); the method of detection was indirect and unamplified. A gas photocell developed by Stebbins' Illinois colleague Jacob Kunz, was employed. The blue-sensitive potassium hydride photocathode Kunz cell, equipped with filters centered at 4,300 Å and 4,800 Å, achieved much higher sensitivities than the selenium cell. It used an inert gas in a partially evacuated cell (1 mm Hg pressure) to provide modest amplification, about a factor of 10, through secondary ionizations.

Stebbins concentrated on measurement of variable stars, β Persei, β Aurigae, and δ Orionis, as demonstrations of the new technique. Fundamental stellar parameters are most easily determined using eclipsing binary light curves. Using only geometry, relative radii and luminosities of the stars can be found independent of any details of stellar structure. Colors, if they can be obtained, provide temperatures and, when supplemented by radial velocity measurements, yield bolometric luminosities and masses. Measurement of eclipse light curves was limited to visual estimates, which had both systematic and large random uncertainties, or photographic observations that could not handle some of the shorter period systems. Stebbins's introduction of photoelectric photometry eliminated both problems. Observing Algol in 1910, he was able for the first time to detect the secondary eclipse, which he measured at about 0.06 magnitudes, and also a small but distinct variation in the brightness of the binary outside eclipse that he attributed to reflection effects. These and subsequent observations served as the basis for **Henry Norris Russell**, **Harlow Shapley**, and **Joseph Moore**'s work on rectification of eclipsing-binary light curves.

Under Stebbins's leadership, Wisconsin became a center for photometry. With his students Charles Morse Huffer and **Albert Whitford** (and later **Gerald Kron** and Olin J. Eggen), Stebbins made major contributions to both binary star and variable-star photometry, obtaining the first accurate light curves for many Cepheid variable stars and compiling standard star magnitudes.

As early as 1915, Stebbins suggested that observations of reflected sunlight from solar-system bodies could be used to study possible variations in the solar constant. **Cleveland Abbe** and **Samuel Langley** initiated long-term monitoring of the solar irradiance from the ground, but uncertainties in atmospheric corrections and the problem of dealing with an extended solar disk plagued the analysis. Stebbins argued that measurements of Jovian satellites and the outer planets, which could be treated as independent point sources, could provide an alternative means for assessing the constancy of the solar luminosity. He conducted the first photoelectric observations of the Jovian moons, in 1926, and found that they have complex, phase-dependent albedos. Although not especially useful for direct study of the Sun, these measurements provided early indications of complex surface structure on small bodies in the Solar System.

During the 1920s and 1930s, Stebbins concentrated on measuring colors for B stars. Following **Robert Trumpler**'s 1930 discovery of interstellar reddening using photographic techniques, Stebbins and Whitford, in 1932, obtained photoelectric measurements that both determined the color dependence of the extinction and revised the globular cluster distance scale. Their measurement of the wavelength-dependent extinction law was a basis for **Jesse Greenstein** and **Louis Henyey**'s and Hendrich van de Hulst's theoretical work on dust grain optics. Stebbins and Whitford extended the sample to early-type stars and mapped the extinction zone for the Galaxy, showing that it corresponds to the Zone of Avoidance found for galaxies. Subsequently, during the war, Stebbins introduced the six-color system (3,530–10,300 Å) with which he and Whitford refined the reddening law and which he used to determine the phase-dependent temperature variations for δ Cephei and later, with Kron, for many other sources. Further improvements came after 1950 with the introduction of the 1P21 photomultiplier and the development by Harold Johnson and **William Morgan** of the UBV filter system, but Stebbins' work was the foundation on which all subsequent photometry was based and serves as the only precision record of the behavior of many stars over a century baseline.

Stebbins also pioneered the photoelectric observations of the solar corona and nebulae and extragalactic systems. Some of the work on nebulae was done with Whitford; they developed a new technique for photometry of extended sources, which they later applied to measuring colors of distant galaxies, looking for changes with time and finding what was called the Stebbins–Whitford effect. The Stebbins–Whitford effect, if it had proven correct, would have been the first evidence that galaxies had been significantly different in the past from the present. They believed that they had shown galaxies at a redshift of 0.1–0.2 to be much redder than zero-redshift galaxies, but the result was an artifact of the particular color bands used and the non-blackbody shape of galactic spectra moving through them (K correction). Such galaxies are, in fact, slightly bluer than contemporary ones, because they contain more young stars.

Stebbins was also an innovator in the study of light pollution and the modern effort to preserve dark astronomical sites. His photoelectric measurements of ambient light from Los Angeles and Pasadena, California, of Mount Wilson and Palomar Mountain, during 1931/1932 are the first quantitative measurements of night-sky brightness caused by urban sources.

Stebbins had a broad natural curiosity. This is evident from some of his minor papers. Examples include a paper with **Edward Fath** on using astronomical telescopes and parallax to study the altitudes of migrating birds, a report of auroral observations during the spectacular display in 1918, and an observation of the green flash from Mount Hamilton.

Stebbins's work received broad, early recognition. He was awarded the Rumford Prize of the American Academy of Arts and Sciences (1913) and the National Academy of Sciences' Henry Draper Medal (1915) for his work on development of photometric detectors, the Bruce Medal of the Astronomical Society of the Pacific (1941), the Gold Medal of the Royal Astronomical Society (1950), the Russell Prize of the American Astronomical Society (1956), and additional honorary degrees from the Universities of Chicago and California for his broad contributions to astrophysical photometry. He was elected to the United States National Academy of Sciences in 1920. Stebbins also served the American Astronomical Society in several offices, eventually as president (1940–1943).

Steven N. Shore

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Stephan, Jean-Marie-Édouard

Born **Sainte-Pezenne, Deux-Sèvres, France, 31 August 1837**
Died **Marseilles, France, 31 December 1923**

Édouard Stephan is chiefly remembered as the director of the Observatory of Marseilles (1873–1907), where he discovered many new nebulae at a time when astronomers were vacillating about whether these were gas clouds in the Milky Way or separate large stellar systems; in fact there are some of each. He also made pioneering studies of the angular diameters of stars.

Stephan graduated at the top of his class from the École Normale Supérieure in 1862 and was promptly recruited by **Urbain Le Verrier** of the Paris Observatory. Three years later, he completed his *docteur ès sciences* degree. In 1866, Stephan was assigned to complete a transfer of the Observatory of Marseilles from the Montée des Accoules to its new site on the Plateau Longchamp. In 1873, he was appointed the observatory's official director. Stephan was also named professor of astronomy in the university of Marseilles in 1879. He held both appointments until his retirement in 1907.

At the Observatory of Marseilles Stephan's principal achievement was to catalog several hundred new "nebulae" (most of which are distant galaxies) and to measure their positions using **Léon Foucault**'s 80-cm silvered-glass reflecting telescope. Because he believed nebulae to be very distant objects, Stephan attempted to use them as fixed reference points against which to measure stellar proper motions within the Milky Way Galaxy. This strategy, however, would not be successfully accomplished before the mid-20th century (with the advent of the Lick Observatory proper motion survey, inaugurated by director **Charles Shane**).

Stephan recognized that many of his (and most other) nebulae were often found in clusters – a fact that might indicate whether gravitational attraction existed far from the Galaxy. One of these clusters, centered upon NGC 7318 in the constellation of Pegasus, is still known as Stephan's quintet. More recent research has shown that one of the five galaxies comprising it exhibits a very different redshift from the other four, despite the appearance of "bridge-like" connections linking it to the rest.

In the early 1870s, Stephan placed two parallel slits in front of the 80-cm reflector, in an attempt to measure the angular diameters of stars by means of their interference fringes. This technique had been suggested by French physicist **Armand-Hippolyte Fizeau**. Stephan found that stellar angular diameters were in all cases less than 0.16 arc seconds. It would be almost 50 years before Americans **Albert Michelson** and **Francis Pease** succeeded in measuring the angular diameter of Betelgeuse with a stellar interferometer.

Stephan's other contributions include transit timings, eclipse and cometary observations, the discovery of minor planet (89) Julia, and work on the longitude difference between France and Algeria. Appointed *Chevalier* (1868) and *Officier* (1879) of the *Légion d'honneur*, Stephan was also elected a correspondent of the Paris Académie des sciences (1879).

William Tobin

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Stern, Otto

Born **Sohrau (Zory, Poland), 17 February 1888**
Died **Berkeley, California, USA, August 1969**

German–American experimental physicist Otto Stern is remembered for the Stern–Gerlach experiment (1922), which established the reality of space and angular momentum quantization, though his 1943 Nobel Prize in Physics was awarded for later work in developing the molecular beam technique and discovering the anomalous magnetic moment of the proton (directly responsible for the wavelength of the 21-cm transition of neutral hydrogen in the interstellar medium). Stern received a Ph.D. in physical chemistry from the University of Breslau in 1912, went as a postdoctoral associate to **Albert Einstein** in Prague, and moved with Einstein to Zürich in 1913, where he became an unsalaried *Privatdozent* (lecturer) at the Federal Institute of Technology [ETH]. In 1914, Stern became a *Privatdozent* at Frankfurt and returned there after service in World War I to Max Born's Institute for Theoretical Physics, soon switching to experimental projects.

Born had difficulty finding money for the Stern–Gerlach experiment, which was partially paid for by American financier Henry Goldman (1857–1937) of Goldman Sachs & Company. Stern was appointed to a professorship at Rostock (1921/1922) and then at Hamburg in 1923, in physical chemistry. In 1933, it became advisable for both him and Born to leave Germany, which they were able to do with financial assistance, again from Goldman. It was at Hamburg that Born did the work on molecular beam spectroscopy for which he received the Nobel Prize. His experiments also directly demonstrated the wave-like nature of whole atoms and molecules. (The wave–particle dualism for electrons had been shown by the earlier Davisson–Germer experiment.) The best known of Stern's younger associates there was Isidor I. Rabi (Nobel Prize: 1944), who brought molecular beam techniques to the United States. Stern became research professor of physics at the Carnegie Institute of Technology in Pittsburgh in 1933 (and an American citizen soon after), but it was never an entirely happy relationship, and he retired in 1945 to Berkeley, California, where he had friends in the physics community, but no opportunity to work in the laboratory or with students. Stern received honorary degrees from ETH and from the University of California, Berkeley. He never married.

Virginia Trimble

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Sternberg [Shternberg], Pavel Karlovich

Born **Orel, Russia, 2 April 1865**
Died **Moscow, (Russia), 1 February 1920**

Pavel Sternberg's career featured diverse scientific, educational, and political accomplishments. The son of a tradesman, Sternberg graduated from the Orel Gymnasium in 1883 and then entered Moscow University in the Faculty of Physics and Mathematics. He assisted **Fedor Bredikhin** in cometary research at the university's observatory. For his investigation of the longevity of Jupiter's Great Red Spot, Sternberg was awarded a gold medal in the year of his graduation (1887).

Sternberg subsequently prepared for an academic career. He earned a master's degree (1903) with a study on polar motion and its influence upon the observatory's latitude. Sternberg was also awarded a doctoral degree (1913) with a thesis on the theory and practice of photographic astrometry, derived from work with the observatory's 15-in. double astrograph. His other principal interest concerned gravimetry, or the precise measurement of the Earth's gravitational field, and its practical applications for subsurface prospecting. Sternberg taught physics at the Kreimer Gymnasium (1887–) and became a *Privatdozent* (lecturer) at the University of Moscow (1890–). He supported the education of women students at a time when tsarist law forbade the practice. For a brief time (1916/1917), Sternberg succeeded **Vitol'd Tserasky** as director of the Moscow University Observatory.

Sternberg's prerevolutionary activities in the Bolshevik's favor permitted his name to become widely known in political circles. After the October Revolution, Sternberg held some influential positions in

Moscow, one of which was within the People's Commissariat for Education. He was further drawn into the Civil War and was appointed as the Red Army's Commissar for the east front in Siberia. While there, Sternberg fell through the ice of the Irtysh River, caught a heavy cold, and died soon after returning to Moscow.

Although his scientific accomplishments were modest, Sternberg's memory was kept alive through later unification of three small Moscow astronomical bodies into a single organization under the aegis of Moscow University (1931). This new research establishment was named the Sternberg State Astronomical Institute [GAISh]. Many revolutionary names were erased in Russia after the 1991 collapse of the former Soviet Union, but the Astronomical Institute of Moscow University continues to exist as the Sternberg Institute. In accordance with a Soviet proposal, Sternberg's name was applied to a feature on the Moon's farside.

Alexander A. Gurshtein

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Stetson, Harlan True

Born **Haverhill, Massachusetts, USA, 28 June 1885**
Died **Fort Lauderdale, Florida, USA, 14 October 1964**

American observer and popularizer of astronomy Harlan Stetson was particularly interested in tracking the effects of solar activity on propagation of radio waves in the Earth's upper atmosphere. The son of Henry Allen Stetson and Jennie Sarah Rowe, he studied at Brown University (B.A.: 1908), Dartmouth College (Sc.M.: 1910), and the University of Chicago (Ph.D. in astrophysics: 1915). Stetson married Florence May Brigham on 4 September 1912; they had three children, Helen, Florence, and Harold. During his graduate training, Stetson was an assistant at several schools, as well as an instructor at Northwestern University and Dearborn Observatory in 1913/1914 and in 1916. His observational training took place at Yerkes Observatory.

In 1916, Stetson moved to Harvard University as an instructor in astronomy, being promoted to assistant professor in 1920. During his stay there, he published *A Manual of Laboratory Astronomy* (1928). Stetson left Harvard in 1929 to become professor of astronomy at Ohio Wesleyan University and director of the new Perkins Observatory. The following year, Stetson was also appointed an instructor at Ohio State University. His formal academic career ended in 1934 when he resigned, though Stetson retained a link to universities as a research associate (Harvard: 1933—1936; and Massachusetts Institute of Technology: 1936–1949).

In 1940, Stetson established his own Laboratory for Cosmic-Terrestrial Research in Needham, Massachusetts, and operated it for the next decade. He was a fellow of the American Association for the Advancement of Science and a member of the American Academy of Arts and Sciences and the Royal Astronomical Society.

As an instrumentalist, Stetson designed a photometer that could measure stellar magnitudes from photographic plates. He was responsible for the initial operation and testing of the 69-in. reflector, then one of the world's largest telescopes, at the Perkins Observatory. Stetson's most sustained interest was solar astronomy, and he participated in six solar eclipse expeditions. Solar-terrestrial connections became a specialty, leading to the publication of *Sunspots and Their Effect* (1937) and *Sunspots in Action* (1947). His interest in radio led to research into solar effects upon radio reception, resulting in *Earth, Radio and the Stars* (1934).

Stetson could be a quick, original thinker. For instance, his suggestion (quoted in the *Los Angeles Times* dated 1 November 1930) that ice ages might be caused by the Solar System passing into interstellar dust clouds dense enough to block some sunlight was made very shortly after the 1930 discovery of interstellar absorption by **Robert Trumpler**.

Stetson was a popular writer and speaker. His *Man and the Stars* (1930) was widely read. Stetson inaugurated the quarterly magazine *The Telescope* at Perkins Observatory in 1931, transferring it to Harvard in 1934 when he left Ohio. The magazine was combined with the younger *The Sky* by **Charles Federer** in 1941 to found *Sky & Telescope*.

Richard A. Jarrell

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Stevin, Simon

Born **Bruges, (Belgium), 1548**
Died **The Hague, The Netherlands, March–April 1620**

Textbook author Simon Stevin was born in Bruges (in what is now Belgium) in 1548, the illegitimate child of Anthuenis Stevin and Catelyne vander Poort. Very little is known of Stevin's youth and education. His first job was in Antwerp as a bookkeeper and cashier in one of the city's trading houses, where he became acquainted with business practice and methods. In 1577, Stevin accepted a post with the financial administration of the Brugse Vrije, the region around the city of Brugge. A few years later we find him registered in Leiden, in the present-day Netherlands. Exactly why he immigrated to the North is not known; perhaps he disliked the Spanish oppression of the southern part of the Low Countries, or he may have had Protestant sympathies. In 1583, Stevin's name appears on the roll of the newly founded University of Leiden, where the young Prince Maurits of Orange was attending courses. From 1590 onward, Stevin worked mainly in the service of Prince Maurits.

In about 1614, at the age of 66, Stevin married the much younger Catharina Cray. They had four children: Frederic, Hendrik, Susanna, and Levina. The second son, Hendrik, published some of his father's works posthumously.

Stevin was the first to produce a complete description of decimal fractions and the operations that can be carried out with them in a pamphlet entitled *De Thiende* (The disme, 1585), in which he also dealt with their practical applications in surveying, the measurement of weights, and the subdivision of money. The Scottish mathematician and theological writer **John Napier** also drew on Stevin's work in his invention of logarithms.

In his works on physics, Stevin was again a fount of new and innovative ideas. In *De Beghinselen des Waterwichts* (The elements of hydrostatics, 1586) Stevin gave an improved demonstration of **Archimedes**' law about the upward force acting on a body immersed in a liquid. He also succeeded in calculating the force exerted by a fluid on the bottom and walls of the vessel in which it is contained. And this led him to formulate the so called hydrostatic paradox many years before Blaise Pascal, to whom it is usually attributed.

In 1586 Stevin published his experiment in which two spheres of lead, one 10 times as heavy as the other, were dropped from a tower in Delft, fell 30 ft. and reached the ground at the same time. Stevin's report preceded **Galileo Galilei**'s first treatise on gravity by 3 years and his theoretical work on falling bodies by 18 years.

Between 1605 and 1608, the textbooks he had produced for Prince Maurits in numerous sciences (algebra, geography, astronomy, bookkeeping, statics and hydrostatics, perspective, *etc.*) were collected and published under the title *Wisconstighe Gedachtenissen* (Mathematical memoirs). Stevin supported **Nicolaus Copernicus**' heliocentric theory in *De Hemeloop* (1608), in which he showed planetary motions in both the Ptolemaic and Copernican systems. He also described how to determine the location of a place on the Earth's surface by knowing its geographical latitude and the magnetic variation of the compass needle. This method proved extremely valuable to the ships of the Dutch East India Company.

Jozef T. Devreese and *Guido Vanden Berghe*

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Stewart, Balfour

Born **Edinburgh, Scotland, 1 November 1828**
Died **Ballymagarvey, Co. Meath, Ireland, 18 December 1887**

Balfour Stewart made pioneering contributions to the study of radiant heat, investigated solar-terrestrial relationships, and constructed a physical model of the solar cycle. The son of a tea merchant, Stewart was first educated in Dundee, and at the early age of 13, entered Saint Andrew's University. He subsequently transferred to the University of Edinburgh, where he studied natural philosophy under James David Forbes. Under parental pressure, he left the university at age 18 to undertake a business apprenticeship in Leith, which was followed by a commercial venture in Australia.

Having finally decided to opt for physics over business, Stewart returned to Britain, first for a brief stay at Kew Observatory, and, starting in 1853, as an assistant to Forbes at the University of Edinburgh. In 1859, he left Edinburgh to take on the directorship of Kew Observatory. It was during his Kew years that Stewart married Katharine Stevens, daughter of a London lawyer. He was elected to the Royal Society of London in 1862, elected to the Royal Astronomical Society in 1867, and was awarded the Royal Society's Rumford Medal in 1868. By 1870, growing tensions with the Royal Society regarding research priorities at Kew led to his resignation and acceptance of the physics professorship at Owens College in Manchester. That same year, Stewart was caught in a railway accident, suffering severe injuries from which he never fully recovered. He died while spending the Christmas holiday.

Stewart was an experimental physicist, and his most noteworthy scientific contributions were in the areas of thermodynamics. His work on this subject culminated in 1858, when Stewart read to the Royal Society of Edinburgh a groundbreaking paper putting forth a "theory of exchanges," according to which bodies radiating heat (*i. e.*, infrared radiation) at certain wavelengths also tend to absorb preferentially at those same wavelengths. Under the assumption that radiation is more than a mere surface phenomenon, but in fact pervades the interior of bodies, Stewart consistently explained his experimental data on the emissive and absorptive powers of thin plates. This was a striking anticipation of the radiation laws independently discovered a few years afterward by German physicist **Gustav Kirchhoff**. However, the greater generality and mathematical rigor of Kirchhoff's formulation largely eclipsed Stewart's earlier contribution.

Stewart was fascinated by the possibility of causal relationships between periodic phenomena in the Sun and Earth. Throughout his life, he carried out a number of investigations that sought to link meteorological phenomena to terrestrial magnetism. It was in this overall context that he made his most important contribution to astronomy, namely the development of a sunspot cycle model based on planetary influences. Stewart's approach was largely empirical; the underlying physical hypothesis was that planetary gravitational perturbations to the solar photosphere, however minute, could perturb the presumably delicate dynamical equilibrium of the solar atmosphere and trigger the formation of sunspots. Between 1864 and 1873, using data from the newly commissioned Kew photoheliograph and working in collaboration with the instrument's designer, **Warren de la Rue**, Stewart discovered a number of apparent correlations between planetary longitudes and the occurrences of sunspot groups. While the whole idea was eventually refuted as more data accumulated and the inferred correlations failed to persist, Stewart's model represented the first quantitative explanation of the sunspot cycle presented during the second half of the 19th century. His ideas were carried further by the British solar astronomer **Annie Maunder**. They have been revived from time to time down to the present, generally without credit to him.

Later in life, Stewart became interested in the scientific study of psychic phenomena, presiding for a time over the Society for Psychical Research. Presuming self-proclaimed "psychics" honest until proven otherwise, Stewart is said to have been repeatedly fooled by assorted illusionists and charlatans. His contemporary attempts at demonstrating, on physical grounds, the immortality of the soul, and the lack of any fundamental incompatibility between science and religion, were met with mixed reviews. But as professor of physics in Manchester between 1870 and 1887, Stewart educated, and with obvious success, a generation of scientific luminaries including Sir Joseph Thomson, **John Poynting**, and Sir **Arthur Schuster**.

Stewart wrote many textbooks on elementary physics that remained popular for many years. His article on terrestrial magnetism in the ninth edition of the *Encyclopædia Britannica* was extremely influential. His efforts at reconciling scientific and religious ideas were laid out in his 1875 book, *The Unseen Universe*, coauthored with Peter Guthrie Tait and first published anonymously.

Paul Charbonneau

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Stewart, John Quincy

Born **Harrisburg, Pennsylvania, USA, 10 September 1894**
Died **Sedona, Arizona, USA, 19 March 1972**

John Stewart was in succession an accomplished engineer, astronomer, textbook author, and advocate of "social physics." He was the son of John Quincy and Mary Caroline (*née* Liebendorfer) Stewart. A graduate of Princeton University (1915), Stewart earned a doctorate in physics from his *alma mater* (1919), after a wartime interruption during which he served with the 29th Engineers in France. Upon completing his studies, he was employed from 1919 to 1921 as an engineer in the department of research and development at the American Telephone and Telegraph Company, New York. His investigations were in the area of speech and hearing, and Stewart is credited with designing the first electronically synthesized "voice."

From 1921 to 1963, Stewart was associated with Princeton University's astronomy department, where he attained the rank of associate professor in 1927. He is probably best remembered among the astronomical community as a coauthor, with **Henry Norris Russell** and **Raymond Dugan**, of the widely used two-volume textbook, *Astronomy*, itself a revision of former Princeton University astronomer **Charles Young**'s *Manual of Astronomy*. Stewart married Lillian Westcott on 17 June 1925. Their son, John Westcott Stewart, followed his father into academia, spending his career as a physicist and administrator at the University of Virginia, Charlottesville.

A highlight of the senior Stewart's astronomical career was the successful observation of a total solar eclipse from the deck of the *S. S. Steelmaker* in the Pacific Ocean during more than 7 minutes of totality on 8 June 1937. This was one of five solar eclipses at which he was present. Stewart's other interests extended to radar observations of meteors, navigation, astrophysics, meteorology, and social physics. Stewart's belief that the laws of physics should have applicability to the social sciences was incorporated into his textbook, *Demographic Gravitation: Evidence and Applications* (1948), which introduced the concept of "potentials of population." He was also the author of two works on navigation.

On Stewart's retirement from Princeton University in 1963, he moved to Sedona, Arizona. Three years later, he was appointed professor of the metaphysics of science at Prescott (Arizona) College, a post he held until just before his death.

Stewart was a fellow of the American Physical Society and the American Association for the Advancement of Science, as well as an honorary fellow of the American Geographical Society. As a member of the American Association of University Professors, he served as its national vice president (1940/1941). Stewart also belonged to the American Astronomical Society, Phi Beta Kappa, and Sigma Xi.

George S. Mumford

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Stewart, Matthew

Born **Rothesay, (Strathclyde), Scotland, January 1717**
Died **Catrine, (Strathclyde), Scotland, 23 January 1785**

Matthew Stewart is remembered primarily for an attempt to deduce the Sun's distance by purely geometrical means. Son of Reverend Dugald Stewart, minister of the parish of Rothesay, and Janet Bannatyne, Stewart received his early education on the Scottish Isle of Bute, then entered the University of Glasgow in 1734, intending to follow his father's wishes by pursuing an ecclesiastical career.

At Glasgow, Stewart turned to mathematics while studying with Robert Simson, with whom he developed a lifelong friendship. Simson's field of study was ancient geometry, specifically an attempt to reconstruct both **Apollonius**'s *Loci Plani* and Euclid's lost three-volume work on porisms. (A porism is essentially a geometrical proposition intermediate between a theorem and a problem; such a proposition, depending on the starting point, is either impossible or possible in an infinite number of ways.) In 1741, Stewart left Glasgow to continue his mathematical education at the University of Edinburgh under one of Simson's former students, **Colin Maclaurin**. Here Stewart deepened his expertise in more modern realms of mathematics, such as calculus and analytic geometry, including astronomical applications. At the same time, Simson periodically communicated his own progress in ancient mathematics to Stewart, who refined these studies on his own.

In 1746, while serving as minister of the parish at Roseneath, Dunbartonshire, Stewart published his breakthrough work, *Some General Theorems of Considerable Use in the Higher Parts of Mathematics*. Some of the work undoubtedly arose from Simson's continuing correspondence with Stewart, but was published with Simson's approval. *General Theorems* established Stewart's reputation in the mathematical community and led to his appointment as professor of mathematics at Edinburgh in September 1747, following Maclaurin's death.

In 1756, Stewart published an essay on a geometric analysis of **Johannes Kepler**'s second law (equal areas). His second book, *Tracts, Physical and Mathematical*, appeared in 1761. Here Stewart analyzed by purely geometrical means the motions of planets, including the perturbations of one planet on another; he further established a geometrical technique to approximate the Sun's distance by considering the observed mean angular motion of the apogee of the Moon's orbit.

The year 1763 brought two further publications – another volume of geometrical propositions plus Stewart's result for the solar distance. That result – 29,875 Earth-radii, or about 119 million miles (191 million km – was much larger than previous determinations and proved controversial. An anonymous pamphlet entitled *Four Propositions* appeared, disputing Stewart's solar distance largely on the basis of the simplifying assumptions he had made. (The pamphlet's author, John Dawson, a surgeon from Sudbury, Yorkshire, England, came forward after Stewart's death.) A harsher attack by John Landen followed in 1771.

His health in decline, Stewart retreated to his estate at Catrine in 1772. Stewart's son, Dugald, carried out his father's duties at the university and, in 1775, was elected to a joint professorship with him.

Stewart was elected a fellow of the Royal Society in 1764. Correspondence between Robert Simson and Matthew Stewart is archived at the University of Glasgow and was published in *The Proceedings of the Edinburgh Mathematical Society* XXI (1902–1903): 1–38.

Alan W. Hirshfeld

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Stöffler, Johannes

Born **Justingen, (Baden-Württemberg, Germany), 10 December 1452**
Died **Blaubeuren, (Baden-Württemberg, Germany), 16 February 1531**

Johannes Stöffler was a German mathematician, geographer, and astronomer. He was professor of mathematics at the University of Tübingen, was canon of the cathedral there, was a teacher (1512–1514) of Philipp Melanchthon, and played a role in the effort to reconcile the Church and astronomical calendars.

Stöffler wrote numerous works, many of which were printed. His *Almanach nova plurimis annis venturis inservientia*, a calendaric work written with the astronomer Jacob Pflaum, was printed at Ulm in 1499 (and reprinted frequently, notably in Venice in 1502 and 1522). Previously Stöffler published *Johannis de Monteregio commentum in Ephemerides*. The *Almanach nova* began the debate and panic over predictions of a universal flood caused by the Great Conjunctions of all the then known planets as well as the Sun in February 1524 in the astrological sign of Pisces. This debate produced over 160 pamphlets in the 5 years before the "fated" 1524. He wrote against such catastrophic predictions, which were often attributed to him after the publication of the *Almanach nova*, in his *Expurgatio adversus divinationum XXIIII suspitiones* printed at Tübingen by U. Morhard in 1523. Stöffler pointed out in his *Expurgatio* that he had always criticized in his astronomy classes the vain and frivolous predictions, which had no scientific foundation, made by some of his contemporary astronomers. He denied that the Great Conjunction in Pisces of 1524 would signify the end of the world or a Universal Flood, neither of which is claimed in the *Almanach nova*.

Invited by Pope Leo X in June 1515 to take part in a project to reform the calendar, Stöffler published *Calendarium romanum magnum caesareae maiestati dicatum*, printed by Jacob Koebel in 1518 at Oppenheim. This was later issued in German as *Der newe gross Roemische Calendar* (Oppenheim, Jacob Koebel, 1531). As a necessary preparation for this calendar reform, he published a number of ephemerides. Stöffler maintained, as did Paul of Middenburg, that the spring equinox should not be a fixed date, as was advocated by George Tanstetter and Andreas Stiborius – with an adjustment of 1 day every 134 years. Instead, using the meridian of Tübingen and the *Alphonsine Tables*, and following the practice of the Church fathers, he suggested a variable equinoctial date for which up-to-date ephemerides were indispensable. Hence, Stöffler published *Opus ephemeridum a capite anni Christi 1532 in alios viginti proximos sequentes ad veterum imitationem accuratissimo calculo elaboratum* *et excussum* (Tübingen, 1513), and *Tabulae astronomicae impressae Tubinge apud Thomam Anshelmum, anno domini 1514.*

Stöffler also published an important tract on the use of the astrolabe, which was successful enough to merit two different translations into Italian in the 16th century – one by Giustiniano Veneto, *Giovanni Stoflerino regola e modi di usare l'astrolabio* (Florence, Biblioteca Nazionale, MS fondo Magliabechi 130), the second by M. A. Gandino in 1563 (Pommersfelden, Staatsbibliothek MS 153 (2713)), published as *Elucidato Fabricae ususque Astrolabii... iam denua ab eodem vix aestimandis sudoribus recognita*, Oppenheim, Iacobo Koebel, 1524.

Stöffler was renowned as a geographer, editing a commentary on the *Sphaera*, which at that time was wrongly attributed to **Proclus**. It was published, according to Gesner, in Tübingen, in 1534.

Stöffler further edited various commentaries on the *Cosmographia* of **Ptolemy**, one published at Tübingen during 1512–1514 – *Commentaria in geographiae Ptolomei libros duos.* The other, entitled *De terrarum orbe habitato in sphaerico artificiato describendo, proiectio prima terrae habitabilis in planum, descriptio orbis habitati per meridianos rectos, tabula revolutionum planetarum de radicum extractione, tabulae astronomicae,* is known only in manuscript (Heidelberg Universitaetsbibliothek MS 234, saec. xvi). Also in manuscript are other ephemerides, *Calendario De Inventione sex solemnitatum Hebreorum* (Tübingen Universitaetsbibliothek, MS 65), and he prepared a *Tractatus trium stellarum* (Munich Universitaetsbibliothek MS n.588, saec xvi).

Graziella Vescovini
Translated by: *Lorenzo Smerillo*

Alternate name

Stoeflerus

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Stoeflerus

Stöffler, Johannes

Stoiko-Radilenko, Nicolas

Stoyko, Nicolas

Stokes, George Gabriel

Born **Skreen, Co. Sligo, Ireland, 13 August 1819**
Died **Cambridge, England, 1 February 1903**

George Stokes was one of the leading figures of 19th-century physics and is chiefly remembered for his theoretical work, especially in hydrodynamics. His name is attached to several physical laws – the

Navier–Stokes equation governing fluid motion; Stokes's law of viscosity, relating the resistance experienced by a body moving in a fluid to viscosity; Stokes's law of fluorescence, which states that the wavelength of the light absorbed by fluorescent materials is always shorter than that emitted; Stokes's (curl) theorem, which applies to fluid dynamics and electromagnetic theory; and (better known to astronomers) the Stokes parameters of polarization for radiation.

Born to an Anglo–Irish family that included many academics and ministers of religion, Stokes obtained his early education at the Reverend R. H. Wall's school in Dublin. He moved to Bristol College, England, at the age of 16. Stokes then entered Pembroke College, Cambridge, in 1837 and graduated first in his class (senior wrangler) in mathematics (1841). Afterward, he became a fellow of the college and was appointed to the Lucasian Chair of Mathematics (1849), the post once occupied by Sir **Isaac Newton**. From his Cambridge days, Stokes became a close scientific colleague of **William Thomson** (Lord Kelvin).

Stokes was made a fellow of the Royal Society of London (1851) and was awarded its Rumford Medal (1854) for his explanation of fluorescence. He was chosen secretary of the society from 1854 until he became its president in 1885. In 1857, Stokes married Mary Susanna Robinson, daughter of the astronomer **Romney Robinson** of Armagh Observatory. The couple had three children. From 1887 to 1891, Stokes served as a Member of Parliament for Cambridge University. He received many medals and academic honors during his career and was made a baronet in 1889.

Stokes sought to explain many natural phenomena involving light waves, was deeply interested in contemporary astrophysical discoveries, and furthered the development of astronomical instrumentation. He discussed the optimization of achromatic lenses and arrived at an explanation of the criterion that **Joseph von Fraunhofer** had employed when designing telescope objectives. In 1852, Stokes employed fluorescence, one of his particular interests, as a means for detecting the ultraviolet spectrum of the Sun. He focused the solar spectrum onto a solution of quinine sulphate, which emitted a blue fluorescence except at the positions of particular absorption lines. Stokes anticipated to some extent **Gustav Kirchhoff**'s discoveries concerning the Fraunhofer lines in the solar spectrum. Yet, because he never published his conclusions on that subject, he refused to claim any credit. In 1852, he introduced a set of four quantities now termed the Stokes parameters, which are widely used to characterize the polarization state of a light wave.

Stokes's prominence in the British physics community led to invitations to serve on many committees. Those of relevance to astronomy included the Committee on Solar Physics and the Board of Visitors of the Royal Greenwich Observatory. He acted as an advisor to the telescope maker Sir **Howard Grubb** and was involved with the unsuccessful British efforts under W. V. Vernon Harcourt to improve the manufacturing of optical glass. As secretary of the Royal Society, he was closely involved in procuring a large telescope for the pioneer astrophysicist Sir **William Huggins**. Stokes was a member of the local committee set up to supervise the manufacture by Grubb of a 27-in. telescope for the Imperial Observatory of Vienna and specified the curvatures for its objective lens.

Ian S. Glass

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Stokley, James

Born **Philadelphia, Pennsylvania, USA, 19 May 1900**
Died **La Jolla, California, USA, 29 December 1989**

American planetarium pioneer James Stokley, son of James and Irene (*née* Stulb) Stokley, received a bachelor's degree (1922) in education and a master's degree (1924) in psychology from the University of Pennsylvania. After graduating, he taught biology and physics at Philadelphia's Central High School and wrote articles for local newspapers. An opportunity to cover the Centenary Dinner of the Franklin Institute in 1924 as a news reporter proved a turning point in his life. At the dinner, Stokley made contacts that led to his employment by Science Service in Washington, District of Columbia, the following year. In 1927, Stokley visited planetariums in Berlin and Jena, Germany, returning with the conviction that he would one day become a planetarium director. Although he had risen to the position of astronomical editor with Science Service in 1931, his earlier ambition was realized when he was appointed director of the Franklin Institute's Fels Planetarium, the second Zeiss-equipped facility to be opened in the United States.

Stokley's programs at the Fels Planetarium at first emulated the cycle of topics devised by **Philip Fox** and **Maude Bennot** at Chicago's Adler Planetarium. However, Stokley's background as a science journalist gave him a sharper appreciation of audience tastes than research astronomers possessed. He was less inhibited about trying new and unconventional topics that were greeted with skepticism by scientific colleagues.

Within a few years, Stokley's original programs had ranked him as the most audacious of astronomical showmen. The techniques he pioneered later became widely adopted among other major American planetariums. For example, astronomers had adopted a theory of planetary conjunctions as the most likely explanation for the Star of Bethlehem. In 1933, Stokley developed a program entitled, "Skies of the First Christmas." Using the Zeiss projector, the succession of conjunctions between the planets Jupiter, Saturn, and Mars, during the period 7–6 BCE, could be accurately reproduced. Scriptural readings, recorded music, and lighting effects, including a crèche scene, were also employed in the program. Stokley's Christmas Star program proved remarkably successful, not only for audiences who witnessed his performances, but among later generations who were exposed to similar presentations at planetariums elsewhere. The Christmas Star became the most widely presented astronomical topic in planetariums, large or small.

In 1936, Stokley presented a program, "How Will the World End?" that earned him a reputation as the greatest showman in the field. After the Christmas Star, no other subject captured such media attention, was so widely copied by other planetariums, or drew such criticism from contemporary astronomers. Either intense heat (from a sudden flare-up) or freezing temperatures (following depletion of its nuclear fuel) were considered possible consequences when the Sun reached the end of its normal evolution. Some astronomers had predicted (incorrectly, it turned out) the possible disruption of our Moon, when tidal friction drew this satellite closer to the Earth. Finally, the remote chance of a collision, between an asteroid or comet and the Earth, was another scenario depicted by Stokely's "end of the world" program. His shows presaged motion picture adaptations of similar themes in the decades that followed.

Stokley then adapted a topic that originated in a 1938 program developed at New York's Hayden Planetarium. This was an imaginary "Trip to the Moon." He prepared visual effects that transformed the planetarium chamber into a space ship. For this, he sought the aid of Dick Calkins, creator of the *Buck Rogers* comic strip, who, it is said, personally designed the control panel that audiences saw on the projected navigator's bridge. While admitting that the rocket trip was "pure fantasy," Stokley defended its educational value on the basis of "absolute scientific knowledge." Through highly creative uses of audiovisual resources, Stokley demonstrated that planetariums could significantly aid popular understanding of astronomy, space travel, and many other scientific wonders.

The 1936 conference of the American Association of Museums gave Stokley an opportunity to report on the economic circumstances under which America's four Zeiss planetariums were administered. It marked the first occasion on which comparative accounts of the incomes, expenditures, and attendances at those facilities were openly discussed. This address highlighted Stokley's prominence within the American planetarium community, along with growing interest among museum professionals in planetariums as public educational institutions.

A close professional relationship developed between Stokley and Hayden Planetarium director, G. Clyde Fisher. The Philadelphia and New York planetariums functioned effectively as a dyad, with frequent exchanges made of program materials and guest lecture appearances. By comparison, larger personal as well as geographic distances separated the directors of the Chicago and Los Angeles planetariums (both professional astronomers) from their eastern colleagues and prevented the formation of a viable professional association.

During this period, Stokley played other roles in the popularization of astronomy. He was invited to witness the pouring of the first 200-in. mirror blank for the Palomar Mountain telescope. In 1935, he had the honor of presenting the first planetarium demonstration ever witnessed by physicist **Albert Einstein**. Stokley observed five total solar eclipses, including that of 8 June 1937 from a cruise ship in the Pacific Ocean.

Stokley served as consultant to, and was later chosen director of, Pittsburgh's Buhl Planetarium and Institute of Popular Science, which opened in 1939. His appointment there was short-lived, however, as he resigned the following year, and withdrew altogether from the planetarium community to became chief publicist for General Electric in Schenectady, New York. He remained in that position from 1941 to 1956. Stokley then joined the faculty of Michigan State University in 1956 as an associate professor of journalism and astronomy, serving in that capacity until his retirement in 1969.

Stokley wrote seven books and many papers in both popular and technical journals. Although his career in planetariums lasted but one decade, he was never far removed from astronomy, and in 1961 the second of his two books on that topic was published. In 1949, Stokley received an honorary Sc.D. degree from Wagner College, Staten Island, New York.

In 1933, Stokley married Susan A. Doughton. The couple had two children, a daughter Marcia and son Donald.

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Stone, Edward James

Born **London, England, 28 February 1831**
Died **Oxford, England, 9 May 1897**

Edward Stone served as Her Majesty's Astronomer at the Royal Observatory, Cape of Good Hope (1870–1879), where he compiled data on more than 12,000 stars for the *Cape Catalogue*. Stone was the son of Edward Stone, a London businessman. Educated at home until the age of twenty, he first attended King's College, London, but then transferred to Queen's College, Cambridge, from which he graduated as fifth wrangler in 1859. Stone was subsequently offered a fellowship from the college.

In 1860, Stone succeeded Reverend Robert Main as chief assistant at the Royal Greenwich Observatory. Over the coming decade, he accomplished a number of duties under director **George Airy**. One of his principal investigations concerned a reanalysis of data from the 1769 transit of Venus, with a view of deriving the most accurate value of the solar parallax (giving the Earth's true distance from the Sun). For this work, Stone was awarded the Gold Medal of the Royal Astronomical Society (1869). In 1866, he married Grace Tuckett; the couple had four children.

Stone was appointed to the Royal Observatory (1870), where he succeeded **Thomas Maclear**. His goal was to prepare a catalog of the positions of all Southern Hemisphere stars down to the seventh visual magnitude from observations made with a transit circle. In addition, he undertook the reduction of extensive observations taken by Maclear. Stone had few paid assistants for this task and was occasionally helped by his wife. While at the Cape, he observed the 1874 transit of Venus, along with the first (16 April 1874) of several total solar eclipses that he would witness during his lifetime.

Having completed his observations for the star catalog in 1879, Stone returned to Oxford, England, where he was appointed the Radcliffe Observer at the University's Observatory (following the death of Main). Stone's publication of the *Cape Catalogue*, containing the positions of 12,441 stars, earned him the Lalande Prize of the Paris Académie des sciences (1881). During the remainder of his career, Stone also published the *Radcliffe Catalogue* of 6,424 northern star positions. He was responsible for coordinating the observations of the 1882 transit of Venus, and for their reduction, from which he derived a value of 8.832 arc seconds for the solar parallax. Stone also attempted, but with only limited success, to employ the technique of minor planet observations suggested by **David Gill** as an independent measurement of the solar parallax. This triangulation method had to await the discovery of the minor planet (433) Eros, which comes closer to the Earth.

Stone served as honorary secretary (1866–1870) and president (1882–1884) of the Royal Astronomical Society and was likewise elected a fellow of the Royal Society of London. He was awarded an honorary doctorate in natural philosophy from the University of Padua (1892).

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Stone, Ormond

Born **Pekin, Illinois, USA, 11 January 1847**
Died **near Manassas, Virginia, USA, 17 January 1933**

Ormond Stone – educator, observatory director, and discoverer of many double stars—was the son of Elijah (a Methodist minister) and Sophia (*née* Creighton) Stone. He grew up excelling in mathematics. After his family moved to Chicago, Illinois, Stone visited the Dearborn Observatory and began a program of studies under director **Truman Safford**. Stone attended, but did not graduate from, the University of Chicago (*circa* 1867–1870); he was later awarded an A.M. degree (1875). He married Catherine Flagler in 1871 and, following her death in 1914, married Mary Florence Brennan in 1915.

Stone's teaching career began while he was still attending the University of Chicago; he served as an instructor at Racine College in Wisconsin (1867–1868) and at the Northwestern Female College at Evanston, Illinois (1869). In 1870, Stone was offered an assistantship at the United States Naval Observatory, which he held until 1875. His work drew admiration from **Simon Newcomb**, who recommended him for the position of director of the Cincinnati Observatory, which Stone held from 1875 to 1882.

Under Stone's direction, the object glass of Cincinnati's 11-in. Merz and Mahler refractor was refigured by **Alvan Clark**. Stone then observed comets and launched a successful program of discovering new southern double stars, of which some 44 of those were recorded in **Robert Aitken**'s *New General Catalogue of Double Stars* (1932). Carleton College astronomer **William Payne** gained a summer's experience in observatory practice under Stone. This opportunity may have sparked Payne's ambition to revive former Cincinnati Observatory director **Ormsby Mitchel**'s periodical, *The Sidereal Messenger*.

Stone was appointed director of the University of Virginia at Charlottesville's Leander McCormick Observatory in 1882. It housed several telescopes, the largest being a 26-in. refractor. Over the next 30 years, he carried out a visual observing program covering a wide range of topics, including the discovery and photometry of nebulae, observations of planetary satellites, variable and double star measurements, and the study of comets.

Stone was a member of several professional societies, including the American Association for the Advancement of Science, and the Washington, Virginia, and Wisconsin academies of sciences. At the University of Virginia, he taught courses in astronomy, established its Philosophical Society, and in 1884 founded the journal, *Annals of Mathematics*, that is still published under the same name. More than 30 Vanderbilt Fellows studied under Stone, including **Heber Curtis**; many went on to successful careers in science. Stone participated in three solar eclipse expeditions, in the years 1869, 1878, and 1900. He published more than 100 papers.

Stone retired from the McCormick Observatory in 1912 to his farm in Virginia, where he continued to be active in the local and state affairs. He died after being struck by an automobile.

Scott W. Teare

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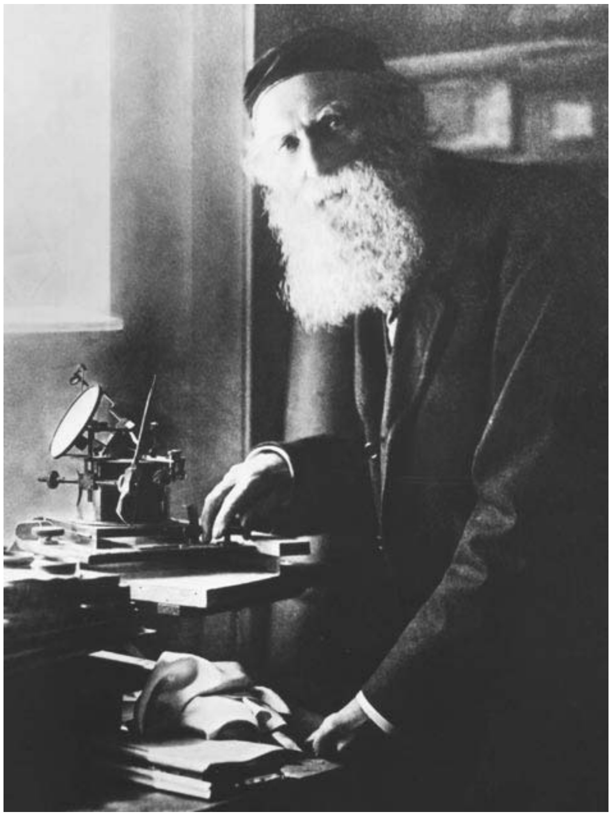
Stoney, George Johnstone

Born **Oakley Park, (Co. Offaly), Ireland, 15 February 1826**
Died **London, England, 5 July 1911**



George Johnstone Stoney was a mathematical physicist with a very wide range of interests. Though most of his working life was taken up with university administration, he made fundamental discoveries in physics and astronomy. He is best remembered for giving the name "electron" to the smallest possible quantity of electric charge.

Stoney was the elder son of George and Anne (*née* Blood) Stoney. The family's rural property in County Offaly greatly depreciated in value after the Napoleonic wars and had to be sold at the time of the Irish Famine (1846–1848). The family moved to Dublin where George and his brother Bindon entered Trinity College, earning their fees by tutoring other students. Both graduated with distinction, George in 1848 and Bindon in 1850. On completing his studies in physics and mathematics, Stoney became the first astronomical assistant to **William Parsons**, the Third Earl of Rosse, spending 2½ years at Parsonstown (Birr), from July 1848 to August 1850 and from August to December 1852. In addition to observing nebulae (most of which turned out to be galaxies) with the great 6-ft. reflector, Stoney served as tutor to Lord Rosse's children.

While at Parsonstown, Stoney prepared for a fellowship in Trinity College. He applied for it in 1852, taking second place and thereby winning the Madden Prize, which was worth about £300. As Stoney could not afford to try again for the fellowship, Lord Rosse used his influence to have him appointed to the Chair of Natural Philosophy at Queen's College, Galway. Stoney remained 5 years in Galway and then became secretary to Queen's University, which brought him back to Dublin in 1857.

As a university administrator, Stoney devoted himself enthusiastically to improving the effectiveness of the provincial colleges in Belfast, Cork, and Galway. It was therefore a great blow to him when the Queen's University was dissolved in 1882 and its place was taken by the Royal University, which had the power of conferring degrees purely by examination. The Irish government frequently consulted Stoney on educational matters, and he was for many years superintendent of civil service examinations in Ireland.

Stoney played a very active part in the affairs of the Royal Dublin Society, serving as honorary secretary from 1871 to 1881 and as vice president from 1881 to 1911. During Stoney's tenure, the society underwent profound changes. It handed over its great collections to the government and received capital to pursue its scientific functions and to improve Irish agriculture. Stoney's own research work was usually communicated first to the society and then reported in its publications and in Royal Society journals. Stoney and his gifted nephew, **George FitzGerald**, played central roles in the society's scientific meetings and discussions.

In 1863, Stoney married his cousin, Margaret Sophia (*née* Stoney); the couple had two sons and three daughters. In spite of the death of his wife in 1872, followed by two severe illnesses of his own (smallpox in 1875 and typhoid in 1877), and his heavy load of administrative duties, he still managed to carry out scientific research, often rising at five in the morning to write or to experiment before going to his office. In 1893, Stoney left Dublin to live in London, in order to give his daughters the opportunity of a university education, which was denied to them at that time in Dublin. On retiring, he developed the lines of research that he had not fully explored while he was occupied with his administrative duties.

One of the main themes of Stoney's research was his interest in the kinetic theory of gases. In a paper published in 1858, he showed that Boyle's law is contrary to the view that the particles of a gas are at rest or that a gas can be a continuous, homogeneous substance. Ten years later, he estimated the number of molecules in a given volume of gas at normal temperature and pressure, independently of a similar estimate by Amadeo Avogadro. In 1868, Stoney first considered the limitations of planetary atmospheres. He correctly explained the absence of hydrogen and helium in the Earth's atmosphere and the absence of an atmosphere on the Moon in terms of the concept of escape velocity. Stoney was also the first to suggest that rotation of the vanes of a Crooke's radiometer arose from the unsymmetrical impacts of molecules contained within the glass envelope.

Stoney introduced the word "electron" (from the Greek word for amber) into the scientific vocabulary. In a paper read before the British Association for the Advancement of Science in 1874, he pointed out "an absolute unit of quantity of electricity exists in that amount of it which attends each chemical bond or valency." He proposed that this quantity should be regarded as the fundamental unit of electricity and suggested the name "electron" in 1881. In the same paper, Stoney proposed the adoption of a system of natural units of mass, length, and time, based on the gravitational constant, the velocity of light, and the electric charge. In 1899, physicist Max Planck proposed a similar set of units that are of significance in cosmology today.

From 1896 onward, Stoney wrote a series of papers concerning the Leonid meteor showers. Together with A. M. W. Downing, he showed in principle how meteor storms could be predicted. More recently, these ideas have been successfully developed to predict the behavior of individual dust trails within the broader streams.

Stoney wrote extensively on the optical theory of microscopes and telescopes, using his concept of spherical wavelets. In 1868, he considered how periodic motions of electrons within atoms could give rise to spectral lines. In later work on the origin of atomic spectra, Stoney proposed that electrons described elliptical orbits in molecules and used this idea to explain double and triple lines in gas spectra.

While primarily a theorist, Stoney was also a practical man. He invented a novel form of heliostat that could be constructed more readily than contemporary instruments of French design. Stoney was keenly interested in music, both scientifically and artistically. By persuading the Royal Dublin Society to hold chamber music concerts, he much enhanced musical culture in Dublin.

Stoney received many honors and distinctions during his life. Perhaps the one he valued most highly was the award of the first Boyle Medal from the Royal Dublin Society in 1899. The medal was instituted to commemorate Irishman Robert Boyle's role in founding the Royal Society of London. Stoney was elected to the Royal Society in 1861, and served as vice president (1898–1899) and on its council (1898–1900). He was a member of the Royal Irish Academy and a fellow of the Royal Astronomical Society. Stoney regularly attended the meetings of the British Association for the Advancement of Science and was president of Section A at the 1879 meeting in Sheffield. He was a visitor to the Royal Observatory at Greenwich and to the Royal Institution, and a foreign member of the United States National Academy of Sciences, and the American Philosophical Society. Stoney received honorary doctorates from Queen's University in Ireland (1879) and the University of Dublin (1902). A lunar crater at 55°.3S, 156°.1W has been named in his honor.

Ian Elliott

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Storer, Arthur

Born **Lincolnshire, England, 1642**
Died **Calvert County, Maryland, (USA), 1686**

As a boy, Arthur Storer was a playmate of **Isaac Newton**. He observed comet 1P/1682 Q1 (Halley) for Newton after immigrating to America.

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Störmer, Fredrik Carl Mülertz

Born **Skien, (Norway), 3 September 1874**
Died **Blindern, Norway, 13 August 1957**

Carl Störmer made substantial contributions to the understanding of polar auroral displays, from both theoretical and empirical viewpoints. His findings also had wider application to the study of cosmic rays.

Störmer was the son of Georg Ludvig Störmer, a pharmacist, and Henriette Mülertz. He attended the national university at Christiania (now Oslo) from 1892 to 1897. Störmer was awarded a *candidatus realium* (graduate) degree in the following year, and then offered a 5-year research fellowship, which allowed him to conduct advanced studies at the Sorbonne (Paris) and Göttingen University. In 1900, he married Ada Clauson; the couple had five children.

Störmer was appointed professor of pure mathematics at the University of Oslo in 1903; he occupied this post for forty three years, until his retirement in 1946. There, his colleague, physicist **Kristian Birkeland**, introduced him to the nature of cathode rays and their behavior in the presence of magnetic fields. Through experiments in which a magnetized sphere was bombarded with cathode rays under vacuum conditions, Birkeland and Störmer were able to simulate a number of phenomena relating to auroral displays. Störmer then undertook detailed analyses of the paths of charged particles in magnetic fields, including numerical integration of differential equations (long before the advent of electronic computation). In 1907, he described one such pathway in which a charged particle becomes entrapped within a dipole converging magnetic field. Although little recognized at the time, Störmer's mathematical solution received dramatic confirmation 50 years later, with **James Van Allen**'s discovery of radiation belts surrounding Earth. These were identified by the United States Explorer I satellite that was launched in 1958 during the International Geophysical Year [IGY].

In 1909, Störmer began intensive photographic studies of the aurorae, using parallactic photography along baselines as large as 27 km. By these means, he established the heights in Earth's atmosphere over which auroral displays occur. His photographic archives eventually encompassed more than 40,000 images. Störmer published a *Photographic Atlas of Auroral Forms* (1930). Results from his career-long research were brought together in his textbook, *The Polar Aurora* (1955).

Störmer was a research associate at Mount Wilson Observatory in 1912. He was appointed chairman of the auroral committee of the International Association of Terrestrial Magnetism and Electricity within the International Union of Geodesy and Geophysics [IUGG], and also chosen president of the auroral committee of the Second International Polar Year (1932/1933). For his auroral research, Störmer was awarded the Janssen Medal of the Paris Académie des sciences (1922). He also received honorary doctorates from Oxford University (which invited him to deliver its 1947 Halley Lecture), the University of Copenhagen, and the Sorbonne. A coeditor of the journal *Acta Mathematica* beginning in 1906, Störmer was elected president of the International Congress of Mathematicians (1936).

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Stoyko, Nicolas

Born **Odessa, (Ukraine), 2 May 1894**
Died **Menton, Alpes-Maritimes, France, 14 September 1976**

Nicolas Stoyko is chiefly remembered for his contributions to the precision measurement of astronomical time and its distribution through the Bureau International de l'Heure [BIH] in Paris, France, which he directed from 1945 to 1964. Stoyko was a student at the University of Novorossia (Odessa). From 1914 to 1916, he was an unpaid trainee at the Odessa Observatory under Aleksandr Orlov, a specialist in polar motion studies. Stoyko received his bachelor's degree in 1916. Soon mobilized into the Russian army (1916–1918), he was certified as *agrégé de mathématiques* in 1920. Unable to obtain a position in his native land, Stoyko immigrated to Bulgaria and taught at a boys' school in Pleven. But following a military *coup d´état* (1923), Stoyko moved to France. Upon a recommendation from his former instructor Orlov, he traveled to the Paris Observatory. In 1924, Stoyko was given a post at the BIH where he spent the remainder of his career.

The BIH had been established in 1919 at the Paris Observatory. Its missions were to centralize astronomical time determinations; to assure the accuracy of all time signal receptions; to distribute a *heure provisoire* (provisional time); and, through data analysis, to publish the *heures définitives* (definitive time), as those quantities were then called. After several years of freelance work and study, Stoyko became *pour ordre et à titre étranger* and made *aide-astronome* (positions available for noncitizens). He became a naturalized French citizen in 1930, under the name of Stoyko, and obtained the title of *docteur d'État français* after defending his thesis, entitled *La mesure du temps et les problèmes qui s'y rattachent* (Measurement of time and related problems, 1931).

In his roles at the Paris Observatory and the BIH, Stoyko contributed numerous astronomical observations, reportedly as many as 100,000. He collaborated with Armand Lambert who was arrested for being a Jew in 1943 and executed at Auchwitz in the following year. In 1945, Stoyko was appointed "*Chef du service horaire*" at the Paris Observatory and *Chef des services* (the nominal director) at the BIH.

During his 40-year career, Stoyko conducted the BIH's longitude campaigns (1926 and 1933) to measure secular changes in the rotation period of the Earth. His work involved improvements to the timekeepers and pendulum clocks (with their constant-pressure cases), along with studies concerning the propagation of radio waves. His investigations into the causes of polar motion led to the creation, under his responsibility, of the Service International Rapide des Latitudes [SIR]. Stoyko's name is associated with the seasonal variations of the Earth's rotation, a phenomenon he disclosed in 1937. Difficult to predict, this effect eventually led to abandonment of the day (= rotation period of the Earth) as the basic unit of time. In the early 1960s, Stoyko introduced an atomic clock into the BIH, which later provided the official time scale established in 1972. When he retired in 1964, astronomers were no longer the only "masters of time."

Appointed *astronome titulaire* in 1946, Stoyko was elected a corresponding member of the Bureau des longitudes and *Chevalier de la Légion d'honneur* in 1952. He was also honored in foreign countries, for example, as a member of the Academy of Technical Sciences in Warsaw (1938–1976). His collaborator and spouse, Anna, reports that during Stoyko's lifetime, he published nearly 300 papers.

Jacques Lévy

Alternate name

Stoiko-Radilenko, Nicolas

Selected Reference

Stoyko, Nicolas (1959). "Proceedings of the Symposium on the Rotation of the Earth and Atomic Time Standards: Part II. The Rotation of the Earth: Variations periodiques et al atoires de la rotation de la Terre." *Astronomical Journal* 64: 99 .

Strand, Kaj Aage Gunnar

Born **Hellerup, Denmark, 27 February 1907**
Died **Washington, District of Columbia, USA, 31 October 2000**

Danish–American astrometrist Kaj Strand pioneered the use of reflecting telescopes for the measurement of parallax and orbits of visual binaries. The United States Naval Observatory, under his direction, completed the first extensive infrared survey (2 μm) in 1969, which found about 3,000 sources.

Strand was the son of Viggo Peter and Constance (*née* Malmgren) Strand; he married Emilie Rashevsky on 10 June 1949, and they had two daughters, Kristin Ragna and Constance Vibeke. Strand received his BA and M.Sc. degrees from the University of Copenhagen in 1931 and his Ph.D. from the same university in 1938 for work done with **Ejnar Hertzsprung** while both were at Leiden, the Netherlands. He became a geodesist with the Royal Geodetic Institute, Copenhagen, 1931. In 1933, Strand was appointed assistant to the director of the University Observatory, Leiden, the Netherlands, where he remained until 1938, working with Hertzsprung. Strand joined the faculty of Swarthmore College, Pennsylvania, USA, in 1938 and remained there until 1946, except for a break for war service in the US Army and US Army Air Force, in which he served with the rank of captain, training special aircrews. Strand became an associate professor at the Yerkes Observatory, University of Chicago, in 1946/1947, thereafter research associate, serving also as professor of astronomy, Northwestern University and director of Dearborn University from 1947 to 1958. In that year, he was appointed director of the Division of Astrometry and Astrophysics at the United States Naval Observatory, becoming the observatory's scientific director in 1963 until his retirement in 1977. Strand also served as a consultant to, among other agencies, the National Aeronautics and Space Administration, the National Science Foundation, the Office of Naval Research, and the National Bureau of Standards.

Upon retirement, Strand received the Navy's Distinguished Civilian Award. He was elected a member of the Royal Danish Academy of Sciences and Letters in 1965. Strand was president of the International Astronomical Union's commission on double stars from 1964 to 1967.

Strand's work with Hertzsprung during his years at Leiden, photographic observations of double stars, influenced him throughout his working life, both in his methods of working and in the topics he selected for research, namely, parallax determinations and basic data on the masses and luminosities of stars and then interpretation of these data, which are of fundamental importance to modern astrophysics. At Swarthmore College, where he worked with **Peter van de Kamp** and his team at the Sproul Observatory, Strand continued in the study of visual binaries, working particularly on the detection of invisible (possibly planetary) companions of those objects. Although many such companions claimed as discoveries by the Sproul group have not withstood further scrutiny, Strand's companion to one of the components of 61 Cygni (now believed to be B) has not entirely been ruled out. At Swarthmore, Strand also pioneered the use of coarse diffraction gratings for accurate measurements of the relative positions of visual binary stars where one star is much brighter than the other.

Astrometry had traditionally been carried out with refracting telescopes of long focal length. Strand became convinced that a large astrometric reflector could provide accurate parallaxes for many intrinsically faint but nearby stars; he first publicly proposed this at a conference he organized at Northwestern University in 1953. When Strand moved to the Naval Observatory, he had the opportunity to create such a telescope. A 61-in. (1.55-m) reflector was commissioned and built at the observatory's station in Flagstaff, Arizona. It came into operation in the spring of 1964 and has continued to produce astrometric measurements of high precision, including a large number of parallaxes. Results from this telescope, which is now known as the Strand astrometric telescope, bear comparison with those obtained so far from space. While he was at the Naval Observatory, Strand also established its first Southern Hemisphere station at El Leoncito, Argentina, where a 7-in. (18-cm) transit telescope was in operation from 1966 to 1973, contributing to the Southern Reference Star Program. He also instituted a long-term program of photographic observations of double stars at the observatory, which he ran from 1958 until 1981.

Alan H. Batten

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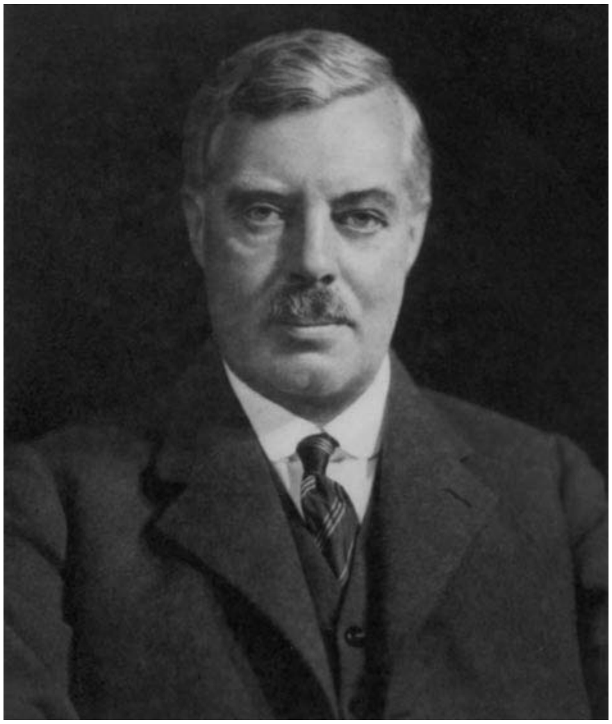
Stratton, Frederick John Marrian

Born **Birmingham, England, 16 October 1881**
Died **Cambridge, England, 2 September 1960**

Frederick Stratton excelled as a teacher, administrator, and international organizer of astronomy and was instrumental in holding together the International Council of Scientific Unions through the difficult years of World War II. His influence on the progress of astronomy as a worldwide enterprise, through his students and international relationships, was perhaps as great as or greater than that of any previous or subsequent astronomer.

The son of Stephen Samuel and Mary Jane (*née* Marrian) Stratton, Frederick never married and had no descendants. He was educated at King Edward VI Grammar School, Five Ways, Birmingham, and Mason College (later to become the University of Birmingham), before proceeding, early in the 20th century, to Gonville and Caius College, Cambridge, with which he was to be associated for the rest of his life. In 1904, the year that **Arthur Eddington** was senior wrangler in the mathematics *tripos*, Stratton was third wrangler. In 1905 Stratton held the Isaac Newton Studentship, and in 1906 he was Smith's Prizeman.



Stratton took some time to find his particular niche in astronomy. His first paper (his essay for the Smith's Prize) was a purely mathematical discussion of the effect of tidal forces on the obliquities of the rotational axes of the planets. After publishing this, he joined the staff of the Cambridge University Observatory, then under Sir **Robert Ball**, and completed a study of the proper motions of faint stars under the direction of **Arthur Hinks**. Stratton then became interested in solar physics and stellar spectroscopy and transferred to the Solar Physics Observatory, recently moved from Kensington to Cambridge. Hugh Frank Newall (1857–1944), the director of that observatory, appointed Stratton as assistant director in 1913, after he had published two papers on the spectrum of Nova Geminorum 1912.

Stratton's astronomical career was interrupted by World War I. He rose to the rank of lieutenant-colonel in the Royal Corps of Signals, and was decorated both by Britain and France, receiving the Distinguished Service Order [DSO], *Croix de Chevalier*, and the *Légion d'honneur*. Stratton returned to the Signal Corps during World War II serving mainly in Special Duties in connection with radio security. He traveled widely in that role, later served as deputy scientific advisor to the Army Council, and was generally known as Colonel Stratton thereafter.

When he returned to Cambridge after World War I, Stratton was appointed tutor at Caius College and relinquished his formal appointments at the Solar Physics Observatory. In those days, the tutor of a Cambridge college was well placed to influence appointments in his own field. Stratton's influence can be measured by the fact that, at one time, the Astronomer Royal, the Astronomer Royal for Scotland, and Her Majesty's Astronomer at the Cape were all graduates of Caius College!

Despite his responsibilities in his college, Stratton maintained a considerable research output. In 1925, he published the book *Astronomical Physics*, one of the earliest textbooks on astrophysics. Although that book is long out of date, one of its appendices remained useful as long as prism spectrographs were in frequent use; it showed how to compute the Hartmann constants necessary for reducing stellar spectrograms.

Novae and solar physics became Stratton's prime interests. In 1926 he went on an eclipse expedition to Sumatra. Stratton led or took part in several other eclipse expeditions but, because of bad luck with the weather, none was as successful as 1926.

In 1928, Stratton succeeded Newall as professor of astronomy and director of the Solar Physics Observatory. The appearance of Nova Herculis in 1934 provided him with another opportunity to study the nova phenomenon spectroscopically; in collaboration with W. H. Manning he produced an atlas of the changing spectrum of that nova. At about the same time Stratton wrote an article on novae for the *Handbuch der Astrophysik*, a multivolume compendium of astronomy that continued to be useful well into the 1960s. Serious stellar spectroscopy rose with the advent of photography in the second half of the 19th century. Spectroscopic observations of novae and of the solar chromosphere during eclipses were, of course, possible only on the rare occasions that novae appeared or total solar eclipses occurred. The early 20th century was, therefore, a time when the groundwork of these two fields of study was laid, groundwork to which Stratton contributed his share.

Stratton frequently stressed the importance of international cooperation in astronomy; his record of service to both national and international organizations shows that he practiced what he preached. A side of his work not generally known was his quiet assistance of astronomers who were victims of political persecution in their own countries.

The esteem in which Stratton was held by the international community is shown in the first two volumes of *Vistas in Astronomy* which, under the editorship of Arthur Beer (1900–1980), were conceived as a tribute to Stratton on the occasion of his 70th birthday; only later did *Vistas* become a continuing serial publication. At that time too, minor planet (1560) was named Strattonia in his honor – a rarer tribute then than it has since become. Stratton was a prominent member of the Cambridge Unitarian Church, of which he was chairman for more than 50 years. Like many physical scientists of his generation, Stratton also had an interest in what are now called paranormal phenomena, and was president of the Society for Psychical Research from 1953 to 1955.

A dedicated member of the Royal Astronomical Society [RAS], Stratton served on the RAS Council for more than 40 years, being elected successively as treasurer (1923–1927), president (1933–1935), and foreign secretary (1945–1955), and for several terms as vice president. He was general secretary of the International Astronomical Union from 1925 to 1935 and was president of Commission 38 (Exchange of Astronomers) for an unusual three terms from 1948 to 1958. Stratton was general secretary of the International Council of Scientific Unions from 1937 to 1952 and also general secretary of the British Association for the Advancement of Science from 1930 to 1935. In 1947, he was elected a fellow of the Royal Society and of the Institute of Coimbra (Portugal). In 1929 Stratton was made an Officer of the Order of the British Empire [OBE], and he was an honorary or corresponding member of several academies and the recipient of a number of honorary doctorates.

Alan H. Batten

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Stratton, F. J. M. and W. H. Manning (1934). *Atlas of Spectra of Nova Herculis*. Cambridge: Solar Physics Observatory.

Streete, Thomas

Born **probably Cork, Ireland, 15 March 1622**
Died **Westminster, (London), England, 27 August 1689**

Thomas Streete was an observational astronomer, a publisher of ephemerides, and introduced, through his writings, **Johannes Kepler**'s laws of planetary motion to **Isaac Newton**. Streete was employed in London as a clerk in the Excise Office under Elias Ashmole. He had contacts with Gresham College, but little seems to be known about his education. He knew a number of the leading astronomers in England and abroad, and often assisted them in observations. Streete was careless about citing his sources, which led to accusations of plagiarism. Still, he published highly regarded ephemerides, worked on the problem of determining longitude at sea, and was engaged in the resurvey of London after the Great Fire of 1666.

Streete was very highly regarded in his own day as an astronomical observer. His tables, even if not described as the best, are regularly cited by Newton in the *Principia*. In 1661, Streete published *Astronomia Carolina*, which provided a list of apparent planetary diameters at their mean distance from us and which disseminated Kepler's first and third laws. In the mid-1660s Newton took nearly *verbatim* notes on Streete's book, which contains the first statement of Kepler's laws that Newton is likely to have seen. Streete presented the third law as exact for the sidereal periods of the planets, which were well determined even in the 17th century, if a value for our distance from the Sun was assumed. Newton's note suggested that he accepted Streete's procedure at that time, developing doubts about the accuracy of the third law only later.

Newton knew that Streete, among others, thought that an equant construction for the planetary elliptical orbits could be explained by quasi-Cartesian vortices. Newton did not learn of the second law (planetary radius vectors sweeping out equal areas in equal times) then, from Streete's treatise, nor did he know of it as early as 1661.

Streete's insistence on the exactitude of Kepler's third law was not based on his own observations but on those made by **Jeremiah Horrocks** and on the latter's value for our distance from the Sun. By 1669 Newton began to worry about the accuracy of Kepler's third law, while he also entertained the hypothesis of vortices. We may conclude that Newton's path to universal gravitation was aided in part by his struggles with the accuracy of Kepler's laws and with the failure of vortices to confirm Kepler's second law. It was Streete among others who had provided Newton with the materials and problems that would eventually lead him to combine inertia with gravitational forces to derive Kepler's three laws.

André Goddu

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Strömberg, Gustav

Born **Gothenburg, Sweden, 16 December 1882**
Died **Pasadena, California, USA, 30 January 1962**

Gustav Strömberg was educated at Gothenburg, Kiel, Stockholm, and Lund universities. From 1906 to 1913, he was an assistant at the Stockholm Observatory. In 1917, he went to the United States and joined the staff of Mount Wilson Observatory.

Strömberg's first important work was on the luminosity of the long-period variable stars . His work on the radial motions of stars and nebulae led to his striking discovery, announced in 1923, of the "asymmetry of stellar motions" explicable in the Lindblad–Oort theory of galactic rotation, enunciated soon afterward.

Strömberg also attempted to correlate radial velocities of nebulae, measured by **Vesto Slipher**, with estimates of their distances, in about 1925. This was before Edwin Hubble established the redshift-distance relation. Strömberg's version included the possibility of negative velocities, so as to include the globular clusters.

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Strömberg, Gustav (1946). "The Motions of the Stars Within 20 Parsecs of the Sun." *Astrophysical Journal*. 104: 12.

Strömgren, Bengt Georg Daniel

Born **Gothenburg, Sweden, 21 January 1908**
Died **Copenhagen, Denmark, 4 July 1987**

Danish astronomer Bengt Strömgren is strongly associated with the concept of the Strömgren sphere, the idea that a star with a certain ultraviolet luminosity can keep a certain mass of diffuse hydrogen gas ionized, thus accounting for the sizes and shapes of the ionized (H II) regions around young, massive stars and the planetary nebulae around old, very hot stars. He was born into a Swedish family, that of astronomer **Elis Strömgren** and dentist Hedvig Strömgren. His father was appointed professor of astronomy and director of the observatory at the University of Copenhagen in 1907, and the son naturally became Danish. Bengt Strömgren married in 1931, and one of their two daughters is the distinguished biologist Nina Strömgren Allen.

As a result of his father's position, Strömgren began observing in 1919; a catalog incorporating some of his measurements was published when he was 17. He received an M.Sc. from Copenhagen University in 1927 and a Ph.D. in 1929 for work on the determination of comet orbits partially carried out with **Karl Kustner**. During the next few years in Copenhagen, Strömgren worked with the physicists at the Institute for Theoretical Physics (usually called the Niels Bohr Institute after its director, **Niels Bohr**), acquiring a familiarity with general relativity, quantum mechanics, and spectroscopy, and working on problems in stellar structure. Among the visitors he interacted with was **Cecilia Payne-Gaposchkin**, whose 1925 thesis had shown that stellar atmospheres have hydrogen as their dominant constituent. In 1932 Strömgren reached the conclusion that hydrogen was abundant also in the interior of stars. He also showed that some of the heavy elements in the Sun have the same relative elemental abundances as they have in meteorites, thus tying stellar astronomy to the work of **Viktor Goldschmidt** on abundances in the meteorites.

Strömgren spent the years 1936–1938 at the University of Chicago as assistant, then associate professor of astronomy, working with **Subrahmanyan Chandrasekhar** and **Otto Struve** on problems of stellar structure and composition. He returned to Copenhagen in 1938 as professor of astronomy and was appointed director of the observatory in 1940 upon his father's retirement. This retirement was marked by an outstanding *Festschrift*, which included a paper by young Strömgren on the structure of the solar atmosphere, incorporating the work of **Rupert Wildt** on the importance of the negative hydrogen ion H^- for solar opacity. His classic paper on ionization of interstellar hydrogen dates from 1939. During the war years, he worked in relative isolation and with limited resources at Copenhagen Observatory on stellar atmospheres, geometrical optics, and calculation of tables useful in both these fields.

After World War II and several short visits to the United States, Strömgren returned to Chicago as professor of astronomy in 1951, and from 1952 to 1957 was also the director of Yerkes and McDonald observatories, before becoming professor of astrophysics at the Institute for Advanced Study in Princeton. His best-known work from this period was in photoelectric photometry in a system he invented (called Strömgren colors) to determine the temperatures, gravitational fields, and compositions of a wide range of kinds of stars. Strömgren colors were incorporated into the new Copenhagen Observatory system when he returned there in 1967.

Meanwhile, more of Strömgren's attention went into scientific administration. He was general-secretary of the International Astronomical Union during 1948 to 1952 and its president during the period 1970–1973. He was elected president of the American Astronomical Society, but his term was curtailed by his return to Denmark, and president-elect **Albert Whitford**, with whom Strömgren had worked on photoelectric colors at Lick Observatory, took over a year early. Strömgren was active in the development of Kitt Peak National Observatory while in the United States and the European Southern Observatory after his return to Denmark. He received medals from the Franklin Institute, the Astronomical Society of the Pacific, the French Academy of Sciences, and the Royal Astronomical Society (London). In 1967, Strömgren was selected as the outstanding scientist of Denmark, entitling him and his family to residence in the Carlsberg Mansion, formerly occupied by Bohr.

Helge Kragh

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Strömgren, Svante Elis

Born **Hälsingborg, Sweden, 31 May 1870**
Died **Copenhagen, Denmark, 5 April 1947**

Early in the 20th century, an often asked question about comets was whether they originate beyond the Solar System – perhaps in other stellar systems. Elis Strömgren endeavored to calculate the eccentricity of comet orbits backward in time, taking planetary perturbations into account. None of the comets examined by Strömgren appeared to have an initial hyperbolic orbit.

At the Copenhagen Observatory, Strömgren's program to communicate timely astronomical information to colleagues in other countries evolved into the International Astronomical Union's Central Bureau for Astronomical Telegrams (transferred to Harvard College Observatory when Denmark fell to the Nazis at the outset of World War II). Strömgren was a colleague of **Carl Burrau** and the father of astronomer **Bengt Strömgren**.

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Stroobant, Paul-Henri

Born **Ixelles, Belgium, 11 April 1868**
Died **Brussels, Belgium, 15 July 1936**

Paul Stroobant directed the Royal Observatory at Uccle, Belgium, and contributed to a number of astronomical specialties, including the study and discovery of minor planets. Before he was twenty years old, he observed the bright comets of 1882 (C/1882 RI) and 1885 and became a voluntary assistant at the Royal Observatory. Stroobant earned a doctorate in mathematics and physics from the University of Brussels in 1889. During the following year, he studied at the Sorbonne, Paris and the Observatoire de Paris.

In 1891, Stroobant returned to Belgium and joined the staff of the Royal Observatory as assistant astronomer. He was to spend the remainder of his career there, becoming in succession assistant director (1918) and director (1925), succeeding Georges Lecointe. He retired only a few weeks before his death. Stroobant also served as professor of astronomy at the University of Brussels after 1896. He presided over its faculty of sciences between 1906 and 1909.

Among Stroobant's most important work was his statistical investigation of the minor planets, based upon more than 800 known objects. From this sample, he estimated the existence of more than 100,000 asteroids brighter than 20th magnitude and calculated their total expected mass.

Stroobant conducted a number of other investigations. These included dynamical studies of the satellites of Saturn, the "personal equation" in meridian circle observations (systematic errors in measuring stellar positions that vary from one observer to another), the direction in space of the Sun's motion, and the dynamics and distribution of stars and clusters in the Milky Way Galaxy.

As the observatory's centennial celebration (1935) drew near, Stroobant ordered and installed newer photographic and spectroscopic equipment, particularly relevant to continued research on minor planets. As a result, **Eugène Delporte** discovered a number of new minor planets at the observatory, including two of particular importance. Minor planets (1221) Amor and (2101) Adonis make relatively close approaches to the Earth.

Stroobant presided over the Belgian National Committee on Astronomy and was elected president of the International Astronomical Union's [IAU] Committee on Bibliography. His textbook, *Précis d'Astronomie*, passed through two editions (1903, 1933). Between 1907 and 1920, Stroobant issued the *Annuaire de l'Observatoire Royal de Belgique*, containing reviews of current astronomical research. He was awarded the Lalande Prize of the Paris Académie des sciences in 1921 and made a Commander of the Legion of Honor. Today, the Paul and Marie Stroobant Prize of the Royal Academy of Belgium honors both the subject of this sketch and his wife.

Jordan D. Marché, II

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F. D. R. (1936). "Paul Stroobant." *Observatory* 59: 349–352.

Struve, Friedrich Georg Wilhelm

Born **Altona, (Hamburg, Germany), 15 April 1793**
Died **Saint Petersburg, Russia, 23 November 1864**

Wilhelm Struve (as he was usually known) was the founding director of the Pulkovo Observatory and codiscoverer of stellar parallax. Through his many descendants, he created a family dynasty of Russian-born astronomers across the span of four generations. Struve, the son of Jakob and Maria Emerentia (*née* Wiese) Struve, was educated at the Christianeum in Altona, the gymnasium at which his father was rector, and later at the University of Dorpat (now Tartu) in Estonia (then part of the Russian empire). He studied classical philology and graduated in 1810 but switched to the study of astronomy and received both master's and doctor's degrees in 1813. Struve married Emilie Wall in 1815; the couple had 12 children, the third of whom (and oldest to survive to adulthood) was the astronomer **Otto Wilhelm Struve**, who became his father's successor. After Emilie's death in 1834, Wilhelm Struve married Johanna Bartels, with whom he had another six children. Struve was elected an associate of the Royal Astronomical Society in 1823 and received its Gold Medal in 1826. He became a corresponding member of the Imperial Academy of Sciences (Saint Petersburg) in 1827 and a full member in 1832. Struve was also elected a foreign member of the Royal Society of London (1827).

Struve's childhood and adolescence coincided with the Napoleonic wars; the troubled nature of those times led to his being sent to the comparative safety of Dorpat University, rather than a nearby one such as Kiel or Göttingen. He was attracted to astronomy by the physicist Georg Parrot, who encouraged him to pursue graduate studies in that subject. The university's observatory had just been completed, but its only telescope (a small transit instrument) remained in its packing cases because the professor of astronomy, **Johann Huth**, was too ill to install it. Struve, largely unsupervised, succeeded in installing the instrument and using it to determine the longitude and latitude of the new observatory, which earned him his advanced degrees. He was then appointed extraordinary professor of astronomy. Struve became ordinary professor and director of the observatory in 1820, following Huth's death.

At that time, an astronomer's duties included surveying and geodetic work. Struve was active in a survey of Livland (much of modern Estonia and Latvia) in the years 1816–1818. This task led him to conceive the measurement of an arc of the meridian through Dorpat and stretching from Hammerfest in Norway, to the mouth of the Danube near the modern border between Ukraine and Romania. Spanning more than 25°, this measurement offered a significant contribution to knowledge of the dimensions of the Earth and was to occupy Struve until illness prevented him from undertaking any further scientific work in 1858. In addition, he directed an expedition to measure the difference in levels between the Black Sea and Caspian Sea, although the fieldwork was done by others. Struve also planned to measure a parallel of latitude from the west coast of Ireland to the Ural Mountains, but illness prevented him from doing so.

In 1820, Struve had visited Munich for the purpose of ordering instruments to be used in his geodetic surveys. During this visit, he saw the large refractor of 9 (Paris)-inches aperture that **Joseph von Fraunhofer** was constructing. Struve was able to persuade Dorpat University to purchase this instrument, which determined the course of much of his astronomical career. The "Great Refractor," as it came to be called, was the largest astronomical telescope of its day and arrived at Dorpat in late 1824. It was promptly assembled by Struve, even though Fraunhofer had forgotten to send detailed instructions for its installation. Struve used it principally for making a census of double stars visible in the northern sky, of which he had already published a preliminary catalog. His research marked the first systematic study of these objects since their gravitational binding had been confirmed by **William Herschel**. The results of Struve's survey were presented in the *Catalogus Novus Stellarum Duplicium et Multiplicium* (1827). The catalog contains more than 3,000 pairs, most of which were Struve's own discoveries. Even before its publication, Struve received the Gold Medal of the Royal Astronomical Society.

His success with the Great Refractor, along with his geodetic work, brought him to the attention of the Tsar Nicholas I, who invited Struve to supervise the construction of a major new observatory (Pulkovo) of which he became the first director in 1839. In that year, he and his family left Dorpat and took up residence at Pulkovo, just outside Saint Petersburg. Much of his time in Pulkovo was spent in reducing his measurements of the arc of the meridian and in determining the constant of aberration from observations made with the prime-vertical telescope in Pulkovo. Although Struve equipped the observatory with an even greater refractor of 15-in. aperture, he rarely used that instrument himself and left it mainly to his son, Otto Wilhelm.

The elder Struve also brought one important piece of unfinished business with him – a determination of the parallax of Vega (α Lyrae). While still at Dorpat, Struve had published an important work, usually known by its abbreviated title of *Mensurae Micrometricae* (1837), a collection of his micrometer measurements of double stars made with the Dorpat refractor that is still of value today. In this work, he presented a preliminary value of the parallax of Vega, as determined by comparing its position throughout the year with respect to its much fainter (and presumably more distant) "companion". His result was in good agreement with the modern value, but its uncertainty was sufficiently large that Struve himself did not regard it as definitive. His newer measurements of Vega were not reduced or published until 1840, after **Friedrich Bessel** had published his determination of the parallax of 61 Cygni. Undoubtedly, Bessel's finding provided the first convincing value for a stellar parallax, but Struve shares with him and **Thomas Henderson** the credit for demonstrating almost simultaneously that the measurement of stellar parallax was within reach.

In 1847, Struve published *Études d'astronomie stellaire*, which might be described as one of the earliest textbooks on stellar statistics. It was necessarily tentative because only a few stellar parallaxes had yet been successfully measured. This book tried to extend Herschel's work on the "construction of the heavens." Controversial in its day, Struve's text remains significant today for containing one of the first suggestions that starlight was absorbed by the presence of an interstellar medium. He correctly argued that the absorption of starlight must be considered in any attempt to measure the distribution of stars in space. Struve attempted quantitatively to estimate the amount of absorption and came up with a value of roughly the same order of magnitude as that found nearly a century later by **Robert Trumpler**. Astronomers of Struve's day, however, were unwilling to consider this possibility, and only Trumpler's work eventually convinced them of the reality of the general interstellar absorption.

Apart from his own achievements in astronomy, Struve is remarkable for having created a dynasty of astronomers that included one of his sons, two grandsons, two great-grandsons, and (briefly) one great-great-grandson. Taken together, the Struve family established a record of achievement in astronomy that is rivaled only by the Herschels and the Cassinis.

Struve likewise had considerable talents as a bibliographer. He equipped Pulkovo Observatory with a first-class library, for which he provided the catalog. The library was further enriched by the purchase of **Heinrich Olbers**'s personal collection of books. These works survived the observatory's destruction during World War II, although much of the Olbers collection was damaged or destroyed by a fire in 1997.

As late as 1857, Struve was still completing his report on the measurement of the arc of the meridian. Overwork was taking its toll, and he planned a "rest-cure" in Europe during which he began negotiations for his project to measure the parallel of latitude. Deteriorating health cut short this venture, and Struve became seriously ill in 1858. Although he recovered enough to enjoy a few more years, his capacity for scientific work was never regained. He resigned in 1862 as director of the Pulkovo Observatory, where his son Otto Wilhelm had been the director in all but name for several years. Struve retired to the city of Saint Petersburg.

Alan H. Batten

Alternate name

Struve, Vasily Yakovlevich

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Struve, Georg Otto Hermann

Born **Tsarskoye Selo, Russia, 29 December 1886**
Died **Berlin, Germany, 10 June 1933**

An expert on the Solar System and especially the planet Saturn, Georg Struve was the son of **Karl Hermann Struve** and Olga (*née* Struve) Struve. When Georg was born, his father was an adjunct astronomer at the Pulkovo Observatory. Georg was taken to eastern Prussia when his father became director of the Albertus University Observatory at Königsberg in 1895. Struve attended the humanistically oriented Königsberg Wilhelms-Gymnasium from which he graduated in 1905. He then studied mathematics and astronomy at the universities of Heidelberg and Berlin, where one of his teachers was Julius Bauschinger.

While a student (1908), Struve assisted **Paul Guthnick** in his pioneering astrophotometric observations. He received his Ph.D. in 1910 for an investigation of the orbital motion of minor planet (2) Pallas. Struve dedicated this work to the memory of his grandfather, **Otto Wilhelm Struve**. He married Marie Mock in 1912; the couple had two sons.

During 1911/1912, Struve worked as an assistant in the observatories located at Bonn, Berlin–Babelsberg (under his father's direction), and at Hamburg–Bergedorf. He was then appointed an astronomer in the Wilhelmshafen Naval Observatory (1913–1919), where he was placed in charge of its chronometers and compasses. Using the observatory's 4.8-in. Repsold meridian circle, Struve measured the positions of Saturn and its satellites, sharing an interest in that subject with his father. He likewise observed the positions of more than 500 stars in order to derive their proper motions. Struve returned to the Berlin–Babelsberg Observatory in 1919, where he regularly used its 26-in. refractor for visual observations. He later held the post of professor there until his death.

Starting in 1917, Struve published some ten papers on Saturn, its satellites, and rings, which included a new determination of the planet's equatorial plane, the orbits of its satellites, the periodic disappearance of its rings when seen edge-on, and comparisons of visual and photographic observations of the planet's satellites. Struve observed the eclipses of Jupiter's satellites, measured the diameter of Venus through an application of the theory of contrasts, studied the outer planets and their satellites, and observed the opposition of minor planet (433) Eros in 1930/1931 to improve knowledge of distances within the Solar System. He supplemented his own observational data with that collected during visits to the Johannesburg Station of the Yale University Observatory, South Africa, and to the Lick and Yerkes Observatories in the United States.

Politically, Struve was an active member of the Deutschnationale Volkspartei, which fought unsuccessfully against the Nazis and attempted a restoration of the Hohenzollern monarchy. As a result of the complex political situation in the early 1930s, Struve suffered a nervous breakdown, experienced a pulmonary embolism, and died suddenly.

Victor K. Abalakin

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Struve, Gustav Wilhelm Ludwig

Born **Pulkovo, Russia, 1 November 1858**
Died **Simferopol, Crimea, (Ukraine), 4 November 1920**

An expert on lunar occultations and stellar positions, Ludwig (as he was usually known) Struve was the son of **Otto Wilhelm Struve** and the younger brother of **Karl Hermann Struve**. He completed gymnasium studies at Vyborg in 1876 and entered Dorpat University from which he graduated in 1880. He then moved back to Pulkovo and worked part-time at the observatory, which his father directed. One of his earliest published papers concerned the double star η Cassiopeiae. In 1883, Struve defended his magister's thesis on the star Procyon (α Canis Minoris). Afterward, he was sent abroad to further his scientific education (1883–1885) and worked at the observatories of Bonn, Milan, and Leipzig.

In 1885, Struve took part in the general meeting of the Deutsche Astronomische Gesellschaft (German Astronomical Society) held in Geneva, Switzerland, and visited observatories located at Paris, Greenwich, Leiden, and Potsdam. He returned briefly to Pulkovo before obtaining a position in 1886 at the Dorpat University Observatory. Struve was married to Elsa Elisabeth Grohmann; the couple had four children.

While at Dorpat, Struve devoted himself to the determination of positions and proper motions of stars. He collaborated with the Astronomische Gesellschaft (essentially an international society) in compiling a catalog of stellar positions for the Dorpat zone (from +70° to +75° declination) of the *Astronomische Gesellschaft Katalog*. Struve's doctoral degree was awarded in 1887 for his detailed comparison of stellar positions gleaned from the Bradley–Auwers catalog and the Pulkovo catalogs of 1845 and 1855.

In 1887, Struve estimated the angular rotation rate of the Galaxy to be -0.41 ± 0.42 arc seconds per century, under the assumption of a rigid body rotation. (The modern value of this parameter is -0.58 arc seconds per century at the Sun's distance from the galactic center.) That year, he also participated in Pulkovo's expedition to observe a total solar eclipse from the location of Smolensk. Between 1884 and 1888, Struve observed occultations of stars during total lunar eclipses for the purpose of determining the Moon's precise radius. For these results, published in 1893, he was awarded the first prize of the Imperial Russian Astronomical Society. In 1910, he also received the Society's Glasenapp Prize for his treatment of occultations over the past two decades. Professor Theodore Wittram wrote of Struve (1915) that he "should be considered as the most competent scholar in this field."

Struve moved to Kharkov University in 1894. He was the first professor extraordinarius and later full professor of astronomy and geodesy from 1897 to 1919. He also directed the university's observatory and from 1912 to 1919 was dean of the Faculty of the Physical and Mathematical Sciences. Together with N. N. Yevdokimov and B. I. Kudrevich, Struve observed the positions of selected zodiacal stars used for deriving the positions of minor planet (433) Eros, and of circumpolar stars from +79° declination to the celestial pole. These observations were applied to new determinations of the constant of precession and of the direction of motion of the Solar System. He took an active part in several geodetic projects, including the leveling work by which the Kharkov Observatory was included in the Russian Vertical Control Network, and he conducted measurements with the Rebeur–Pashwitz horizontal pendula.

In 1919, under mounting pressure from political events in post-revolutionary Russia, Struve and his family fled to Simferopol, Crimea. There, he obtained an academic position at the newly founded Tauride University. But grave misfortunes followed him, including the death of his son Werner and a younger daughter. Struve himself died suddenly while attending a meeting of the Tauride Learned Association, where he had gone to present a paper on Nova Cygni 1920. The new star was independently discovered and observed by his son, **Otto Struve**, and strongly influenced the latter's astronomical career.

Victor K. Abalakin

Alternate name

Struve, Ludwig Ottovich

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Struve, Hermann Ottovich

➜ **Struve, Karl Hermann**

Struve, Karl Hermann

Born **Pulkovo, Russia, 3 October 1854**
Died **Kurort Herrenalb, (Baden-Württemberg), Germany, 12 August 1920**

A specialist in optics and planetary satellites, Hermann Struve (as he was usually known) was the son of **Otto Wilhelm Struve** and the elder brother of **Gustav Struve**. He was first educated at the gymnasia of Karlsruhe, Germany, and Vyborg, Russia. After passing his final exams at Revel, Russia (now Tallin, Estonia), he enrolled at the University of Dorpat in 1872, where he studied mathematics and physics. In 1874, Struve took part in Bengt Hasselberg's Pulkovo expedition to eastern Siberia and the port of Possiet to make observations of the transit of Venus. This experience interrupted his studies for almost a year. He graduated from Dorpat University in 1877 and returned to Pulkovo as a part-time astronomer under his father's direction.

To continue his education, Struve traveled to Paris, Strasbourg, Berlin, and Graz. At Berlin, his tutors were **Hermann von Helmholtz**, **Gustav Kirchhoff**, and Karl Weierstrass. While in Graz, he began a thesis under Ludwig Boltzmann's guidance on the problem of Fresnel interference and the diffraction of light, which was completed in 1881. Thereafter, he was awarded his magister's degree *cum lauda* from Dorpat University. In the following year, Struve received his doctoral degree in mathematics, also from Dorpat University, for the elaboration of a new theory of diffraction phenomena, which he tested with apparatus of his own design and construction.

Upon returning to Pulkovo as an adjunct astronomer, Struve conducted precise observations of Saturn's satellites, especially Iapetus and Titan, first with the observatory's 15-in. and, after 1885, with its 30-in. refractors. Upon his father's retirement, Struve served as senior astronomer from 1890 to 1895. During this time, he investigated the dynamics of Neptune, Mars, and Jupiter, observed the positions of planetary satellites, measured double stars, and published works on theoretical optics. He married Olga Struve, the daughter of his father's cousin, in 1885. The couple had two sons, one of whom, Georg Struve, became an astronomer.

To be nearer to his father at Karlsruhe, Germany, Struve accepted the directorship of the Albertus University Observatory at Königsberg in 1895. There, he published his most important work (1898), which provided a complete list of the basic constants of motion related to Saturn's ring and satellite system. Among Struve's discoveries was the recognition of libration motions of two satellite pairs: Mimas-Tethys and Enceladus-Dione.

Struve was awarded the Damoiseau Prize by the Paris Académie des sciences (1897) and the Gold Medal of the Royal Astronomical Society (1903). In 1904, he became director of the Berlin–Babelsberg Observatory and, from 1913 until his death, directed the Neu-Babelsberg Astrophysical Observatory that he helped to found.

Victor K. Abalakin

Alternate name

Struve, Hermann Ottovich

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Struve, Ludwig Ottovich

➜ **Struve, Gustav Wilhelm Ludwig**

Struve, Otto

Born **Kharkov, (Ukraine), 12 August 1897**
Died **Berkeley, California, USA, 6 April 1963**

Russian–American stellar astronomer Otto Struve contributed to our understanding of the spectra of stars and nebulae, binary stars, the interstellar medium, and stellar structure and evolution. He was the great-grandson of **Friedrich Struve,** the grandson of **Otto Wilhelm Struve**, the nephew of **Karl Struve**, and the son of **Gustav Struve**, professor of astronomy at Kharkov University, and his wife Elizabeth.

Otto Struve had begun studies in astronomy at Kharkov University but enlisted in the Imperial Russian Army in 1916. At the end of World War I, he returned to his studies, completing a diploma (BS) in 1919 and then rejoined the army as a lieutenant in the White Russian forces opposing the revolution. When that cause was lost, he and many others fled to Turkey, where Struve attempted to make contact with members of his immediate family (few of whom survived). He got in touch with a German aunt who notified astronomers at the University of Chicago of his survival and circumstances. **Edwin Frost** was able to offer him transport and a position at Chicago and Yerkes, where he completed a Ph.D. in 1923. Struve continued collaboration with Russian astronomers throughout his career, including **Grigory Shain** on stellar rotation and carbon stars, **Boris Gerasimovich** on the interstellar medium (a very important investigation that nearly led to a pre-World-War-II recalibration of the cosmic distance scale), and K. F. Ogorodnikov (on β Cephei stars), though he said later that his inspiration to a career in astrophysics had come from the work of **Henry Norris Russell**.

Struve was appointed an instructor in astrophysics at Yerkes Observatory following his Ph.D. in 1924 and in 1927 became an assistant professor at Yerkes as well as a citizen of the United States. A hard worker, even a driven man, he became an associate professor in 1930, assistant director of the observatory in 1931, and director in 1932. In 1947, he became chairman and honorary director.

In 1950, in declining health, Struve moved to the University of California at Berkeley as head of the astronomy department. He returned home to Yerkes in 1959 and, in the same year, accepted the position of director of the new National Radio Astronomy Observatory in Green Bank, West Virginia. This move was a great surprise to most, for Struve had no experience at all in the field and, at that time, radio astronomy was considered by many to be outside "real" astronomy, a matter best left to amateurs and electrical engineers. Struve knew what he was doing, however, and he gave instant respectability to the discipline, which has flourished ever since.

By 1962, Struve resigned due to a further deterioration of his health, and took dual positions at Princeton University's Institute for Advanced Study and the California Institute of Technology. He died at 65, worn out by his labors. Struve and his wife, the former Mary Martha Lanning, had no children, and so with them the Struve dynasty came to an end.

From 1932 until 1947, Struve was editor of the *Astrophysical Journal*, then as now the premier publication in the field of astronomy. This was a demanding task (at least half time for most people), yet it hardly slowed down his astronomical research. In this position, Struve established and maintained a reputation for rigor combined with openness and fair mindedness.

While at Yerkes, Struve played a key role in the construction of what was then the world's second largest telescope. By 1932 the University of Texas had come into control of an $800,000 bequest of banker William J. McDonald, Paris, Texas, to build an observatory; however, Texas had no astronomy department. Meanwhile, Struve was frustrated by the lack of a large, modern telescope at Yerkes and the large proportion of cloudy nights there. Learning of the McDonald fund, he brokered an agreement whereby the University of Texas would build and own the observatory while the University of Chicago would operate it and pay all ongoing expenses. By the spring of 1939 an 82-in. reflector was in operation at the W. J. McDonald Observatory on Mount Locke in Trans-Pecos, Texas, where the skies are dark and for the most part clear. Struve was director at McDonald until 1947, and during his tenure dealt with the difficult problems involved in keeping it (and, of course, Yerkes as well) operating through World War II and its aftermath.

Despite his onerous administrative and editorial duties, Struve was first and foremost an observational astronomer, with stellar spectroscopy his *forte*. He particularly used spectra of very high dispersion for his era, which could be obtained only with telescopes of large aperture. Struve was not primarily a theoretician. Though he attempted to interpret his observations whenever possible, he made it a point to publish them even when they apparently defied explanation; the case of the massive, luminous, interacting binary β Lyrae is a prime example.

Starting his career by studying the radial velocities of more or less normal spectroscopic binaries, Struve was soon drawn to a lifelong fascination with unusual ones and, indeed, peculiar and even bizarre stars of all types, including variables. Many (but not all!) of his binary-star observations could be explained by invoking the presence of gas streams that transferred material from one star to the other.

Struve worked at a time when atomic physics was coming of age and, often by working at high dispersion, was able to apply and extend many recent advances. For example, he demonstrated the existence and influence of the Stark effect, rapid axial rotation, and turbulence on stellar spectral lines.

In another area, Struve demonstrated that absorption lines of ionized calcium in the spectra of distant stars were due to diffuse interstellar gas clouds. This led him to a general study of the interstellar medium and diffuse emission and reflection nebulae and, in turn, to his detection, with **Jesse Greenstein** of faint hydrogen emission throughout our Galaxy, using a specially designed nebular spectrograph at McDonald.

Struve's work on stellar rotation and gas streaming inspired him to speculate in the late 1940s on their possible roles in the evolution of stars as they age. His conclusion required major revision in light of future understanding of nuclear reactions in stars and post-main-sequence evolution as pioneered by **Martin Schwarzschild**.

Struve served the American Astronomical Society as vice president (1941) and president (1946–1949) and the International Astronomical Union [IAU] as vice president (1948–1952) and president (1952–1955). During the 1955 IAU General Assembly in Dublin, he was able to arrange a compromise whereby the union would meet in the Soviet Union (Moscow) in 1958 and in the United States (Berkeley) in 1961, thereby enabling international cooperation to continue in astronomy where it had ceased in almost all other activities. He was elected to the academies of science in the United States, the United Kingdom, Belgium, the Netherlands, and several other countries, received the Gold Medal of the Royal Astronomical Society, and was awarded nine honorary doctorates.

Struve was a prodigious author, with six books and more than 400 technical papers to his credit, as well as dozens of book reviews and popular articles. **Albrecht Unsöld**'s 1963 obituary notice in *Mitteilungen der Astronomischen Gesellschaft* (pp. 11–22) contains an exhaustive list of Struve's scientific publications, most of which appeared in the *Astrophysical Journal*. In addition, there are two long series of articles on a general level that appeared in *Popular Astronomy* from 1924 to 1951 and in *Sky & Telescope* from 1946 to 1963.

Of Struve's books, the most widely read was *Stellar Evolution: An Exploration from the Observatory* (Princeton University Press, 1950). His speculations in this area were not widely accepted at the time and soon became completely outmoded. However, the observational data presented there are still valid and as fascinating as ever, while the work has great historical value as an illustration of the way one astronomer was thinking at the time when evolution of stars was first seriously considered.

The 82-in. reflecting telescope at McDonald Observatory is named in Struve's honor.

Ronald A. Schorn

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Struve, Otto Wilhelm

Born **Dorpat (Tartu, Estonia), 7 May 1819**
Died **Karlsruhe, Germany, 14 April 1905**

Otto Wilhelm Struve's career spanned 50 years at the Pulkovo Observatory, where he succeeded his father as director from 1862 to 1889. His own work concerned astrometric topics like double stars and precession, but he supported the early development of astrophysics at Pulkovo.

Otto Wilhelm was the third son of **Friedrich Struve** and Emilie (*née* Wall) Struve. Otto Wilhelm received much of his early education at home before proceeding to the University of Dorpat (Tartu), where he also studied under his father. He graduated in 1839, shortly before the family relocated to Pulkovo, where he became one of four associate astronomers. In 1842, he married Emilie Dyrssen, with whom he had ten children, including **Karl Hermann Struve** and **Gustav Struve**, both of whom became astronomers. After Emilie's death in 1868, Otto Wilhelm married Emma Jankowsky in 1871, with whom he had one daughter, Eva.

It is unclear when Struve chose to become an astronomer. His two older brothers died prematurely, leaving him the eldest survivor of his parents' 12 children. He became deputy director of the Pulkovo Observatory in 1854 and assumed added duties after his father's incapacitating illness (1858), being officially appointed director in 1862. Struve's increasing involvement in its administration doubtlessly interfered with his own scientific productivity. He remained director until his retirement in 1889. Struve was elected an associate of the Royal Astronomical Society (1848) and received its Gold Medal in 1850. He was also elected a corresponding member of the Imperial Academy of Sciences (Saint Petersburg) in 1852 and made a full member in 1861. Struve was elected a foreign member of the Royal Society of London (1873) and an honorary member of the United States National Academy of Sciences (1883).

Struve continued his family's tradition of careful work in positional astronomy and in the discovery and measurement of double stars. He had a large share of the time on the new 15-in. refractor at Pulkovo (then the world's largest telescope) and added to his father's discoveries of binary stars. In particular, he discovered the binary nature of δ Equulei, a star that once held the record as the visual binary with the shortest known orbital period. Struve attempted to estimate personal errors by his construction and measurement of artificial double stars.

Struve used the 15-in. telescope for other kinds of observations, too. In 1852, he was perhaps the last person to observe the separated fragments of comet 3P/Biela, as it receded from the Sun. Struve assisted in the observatory's geodetic work, especially its determination of the longitude difference between Altona and Greenwich (1846). This task, which he undertook with Wilhelm Döllen (later his brother-in-law), formed the second half of a longitude determination undertaken between the Pulkovo and Greenwich Observatories. His father had supervised the earlier measurements. After his father became ill, Struve completed publication of the *Arc du Meridien*.

Struve's contemporaries considered his most important work to be new determinations of the constant of precession and of the solar motion. These were published by the Saint Petersburg Academy (1841) and the work awarded the Gold Medal of the Royal Astronomical Society. Astronomer Royal and society president **George Airy** gave a detailed description and analysis of Struve's work at the time of this award.

Despite a reputation to the contrary, Struve encouraged some of the earliest astrophysical observations made at Pulkovo. For example, he attempted spectroscopic observations of the aurora in 1868.

Increasingly, however, Struve became the observatory's administrator and enabled other members of his staff to do the scientific work. He coordinated Russian observations of the 1874 transit of Venus and facilitated an American expedition to the neighborhood of Vladivostok. Struve concluded that further observations of the Venus transit were unlikely to lead to an improved value of the solar parallax and did not organize any official Russian expedition in 1882.

Struve was very active in affairs of the Deutsche Astronomische Gesellschaft (German Astronomical Society), the only organization of its kind that then tried to operate on an international level. He was a prominent member of the International Metre Commission and tried, unsuccessfully, to get Imperial Russia to adopt the Gregorian calendar.

Although Struve was exclusively a visual observer, he was much impressed by the early photographic work of the French brothers **Paul** and **Prosper Henry**, and discussed the possibilities of astronomical photography in correspondence with **David Gill**. He became president of the Astrographic Congress held in Paris (1887) that initiated the photographic *Carte du Ciel* project. His letters, however, show that Struve remained ambivalent about its probable success. Events were to prove him correct, at least after his death, but his initial skepticism contributed to a feeling of isolation from the astronomical community that only increased with time.

Struve's final gift to Pulkovo was the construction of a 30-in. refractor. While the observatory's 15-in. telescope had once been the world's largest, it had long since lost that distinction. In 1878, he was authorized to make inquiries about the cost of a 30-in. refractor, an instrument sufficiently large then to restore Pulkovo's preeminence. United States Naval Observatory director **Simon Newcomb** influenced him to consider letting Alvan Clark & Sons make the telescope. This decision led to Struve's twice visiting the United States of America.

The building of the large refractor and dome encountered a number of delays, but the telescope arrived at Pulkovo in the summer of 1884 and was finally installed in the winter of 1884–1885. Struve made some use of the telescope at the beginning, but concluded that he was no longer strong enough to handle so large an instrument. Its chief user became his son Karl Hermann. The telescope was dismantled during World War II and its dome was destroyed during the siege of Leningrad. It has never been rebuilt.

Struve considered retirement on several occasions, partly because he found himself at odds with the Imperial Academy, which administered the Pulkovo Observatory. He remained in office at the tsar's request until the observatory's 50th anniversary had been celebrated. He then retired to Germany, eventually settling in Karlsruhe. After his second wife's death in 1902, Struve became increasingly infirm.

Alan H. Batten

Alternate name

Struve, Otton Vasilievich

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➔ **Struve, Otto Wilhelm**

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➔ **Struve, Friedrich Georg Wilhelm**

Stukeley, William

Born **Holbeach, Lincolnshire, England, *circa* 1687**
Died **London, England, 3 March 1765**

Physician William Stukeley made studies of Stonehenge and thus foreshadowed the development of archaeoastronomy.

Stukeley, the eldest son in a family of four boys and a girl, was a man of wide interests, and was one of the first antiquaries to value ancient monuments and to show concern about their survival. He was educated at what is now Corpus Christi College, Cambridge, matriculating in 1704 at the age of 17. Although his interest in ancient relics began at Cambridge, Stukeley's investigations really got under way when he was in his 20s and practicing medicine in Lincolnshire. From 1718 to 1725, a period now regarded as the most significant of his archaeological career, Stukeley was very active in fieldwork. He was also a student of solar eclipses, observing the eclipse of 22 April 1715 while in practice in Boston, Lincolnshire; later he also observed the total solar eclipse of 11 May 1724 and the annular eclipse of 1 April 1764.

Stukeley was the first secretary of the Society of Antiquaries, which he helped to found in 1717, and was elected a fellow of the Royal Society in 1718. By the 1730s he was in Holy Orders, producing works of half-religious, half-antiquarian conjecture. Stukeley published, among other writings, *Itinerarium Curiosum* (1724), *Stonehenge, a Temple Restored to the British Druids* (1740), and *Avebury, a Temple of the British Druids* (1743). In 1747 he accepted the rectory of Saint George the Martyr, Bloomsbury, where in 1764 he observed the annular eclipse of the Sun.

In general Stukeley's fieldwork is reliable, but he could be wayward in his judgments. For instance, in 1757 he published as a genuine work of Richard of Cirencester (an authentic figure), Charles

Bertram's forgery *De Situ Britanniae*, which purported to be a history of Roman Britain. Stukeley's measurements of the stone circles at Avebury and Stonehenge were accurate and are still useful. However, he attributed the construction of the latter to the druids, and suggested without evidence that they had used it for esoteric purposes. But even though his ideas became increasingly eccentric, Stukeley was still widely acknowledged as the only antiquary in England interested in the pre-Roman period. Hence, in spite of his elaborate druidical fantasies, Stukeley more than anyone before him correctly placed the great stone circles in a prehistoric context, and unwittingly assisted in laying the foundations of archaeoastronomy.

Richard Baum

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Su Song

Born **Tong'an, (Fujian), China, 1020**
Died **Runzhou (Zhenjiang, Jiangsu), China, 1101**

Su Song was a Chinese astronomer and pharmacologist in the Northern Song dynasty. His public name was Zirong. In 1042, Su Song passed the imperial examinations for government service. In 1086, he was ordered to investigate existing armillary spheres. He examined them and discussed armillary spheres with Han Gonglian, who had made a model of a water-driven armillary sphere. In 1087, Su Song started a project to make a new water-driven armillary sphere with Han Gonglian and others. After making a small model in 1088 and presenting a large model in 1089, Su Song completed the water-driven armillary sphere *cum* celestial globe called *Shuiyun yixiang tai* (tower of water-driven instrument) in 1092. He also composed the *Xin yixiang fayao* (Outline of the method for a new instrument), which is a detailed monograph on this instrument.

The invention of the armillary sphere and celestial globe in China is usually attributed to the time of the former Han dynasty. The inventor of the armillary sphere is said to have been Luoxia Hong, who contributed to the calendar reform (104 BCE) of the Taichu era. At that time, the armillary sphere was used to determine the equatorial system of coordinates. Probably only right ascension was measured initially and the north polar distance added later. At the beginning of the later Han dynasty, the concept of the ecliptic was established, and the first official instrument with an ecliptic circle is said to have been made in the year 103. The celebrated astronomer **Zhang Heng** made an armillary sphere and a celestial globe. The latter is said to have been the first attempt to rotate the celestial globe using waterpower.

The definite form of the armillary sphere was established by **Li Chunfeng** of the Tang dynasty in 633. His instrument contained three sets of rings: The outer set consisted of meridian, horizon, and equatorial rings; the middle set consisted of the rings for the equator, ecliptic, and the orbit of the Moon; while the inner set consisted of the polar axis and a sighting tube. **Yixing** and Liang Lingzan made an armillary sphere around 724. They also made a water-driven celestial globe in 725. The technology of the latter was improved by **Zhang Sixun** of the Song dynasty, who constructed a water-driven (mercury-driven in winter) celestial globe in 979. This was a predecessor of Su Song's instrument. Some armillary spheres were made in the Song dynasty, one of which was constructed by the polymath Shen Gua in 1074, who also wrote monographs on the armillary sphere, water clock, and gnomon. It may be mentioned here that Shen Gua and his colleague Wei Pu also contributed to the development of the calendar.

The technology to produce constant water flow was highly developed in China along with the development of the water clock. The water clock is said to have already been used in the Spring and Autumn and Warring States periods (770–221 BCE). The earliest extant water clocks in China are from the former (western) Han dynasty (206 BCE–8 AD). They are the simple outflow type of water clock. Of course, these simple water clocks cannot achieve a constant water flow, since the water pressure diminishes as the water volume decreases, so that the water flow also diminishes. The first attempt to achieve a constant water flow was made by Zhang Heng in the later (eastern) Han dynasty (25–220). He made an inflow-type of water clock with a double reservoir. Water was supplied by the upper reservoir, and the water level and water flow of the lower reservoir did not decrease much. In the Tang dynasty (618–907), Lü Cai made an inflow type of water clock with fourfold reservoir (where the upper three reservoirs are used to supply water) in the 7th century.

In the northern Song dynasty (960–1127), Yan Su made a kind of ultimate water clock in 1030. In this instrument, water was oversupplied by the upper reservoir to the lower reservoir, the water overflowing through a tube attached to the lower reservoir so that the water level of the lower reservoir is always at the height of the tube. This device was also utilized by Su Song. Actually, a simple siphon cannot achieve a constant water flow, as the water level of the acceptor increases and the difference between the water level of the reservoir and that of the acceptor decreases. In the water clock of Han Zhongtong, made in 1162, water from the reservoir siphon was accepted by a funnel, and then went to the acceptor. In this instrument, the above-mentioned defect was solved.

Su Song's *Shuiyun yixiang tai* was a huge clock tower. It consisted of three stories. The upper story on the roof was for an armillary sphere, the middle story was for a celestial globe, and the lower story was for mechanical devices to rotate the armillary sphere and the celestial globe (and also to move figures to indicate the time, and to signal the time). It had an escapement in order to control the movement.

Su Song's monograph on this instrument (*Xin yixiang fayao)* has a set of five star maps for drawing the celestial globe. They are clearly written, beautiful star maps (one map of circumpolar stars, two maps of non-circumpolar stars expanded around the equator, and a pair of maps of the Northern and Southern Hemispheres).

Alternate name

Su Sung

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Su Sung

➜ **Su Song**

Suárez, Buenaventura

Born **Santa Fe, Argentina, 3 September 1678**
Died **Paraguay, 24 August 1750**

The first native-born astronomer in the Western Hemisphere was Father Buenaventura Suárez, S. J. Assisted by Guarani Indians, Suárez constructed the telescopes for his mission observatory himself (including the grinding of lenses from native crystal) in the 1730s. His Southern Hemispheric observations included those of eclipses, comets, and occultations of Galilean satellites. Late in life, the Jesuits equipped Suárez with European-made telescopes. He wrote an almanac published in Spain and corresponded with **Anders Celsius**, **Joseph Delisle**, and other Old World astronomers.

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Suess, Hans Eduard

Born **Vienna, (Austria), 16 December 1909**
Died **San Diego, California, USA, 20 September 1993**

Austrian–American chemist and physicist Hans Suess, together with **Harold Urey**, compiled the table of abundances of the elements and isotopes in the Solar System that guided Alastair G. W. Cameron and E. Margaret Burbidge, Geoffrey R. Burbidge, **William Fowler**, and **Fred Hoyle** to understanding the origins of the elements, primarily from nucleosynthesis in stars. Suess was the son of Franz E. Suess (1867–1941), professor of geology at the University of Vienna and grandson of Eduard Suess (1831–1914), author of an important early work in geochemistry, *The Face of the Earth*, who had held the same position. Hans Suess's scientific interests were shaped by this background, and he received a Ph.D. in chemistry from the University of Vienna in 1935. After postdoctoral work in chemical institutes at the Swiss Technical University [ETH] and the University of Vienna, he accepted a position at the University of Hamburg in 1938.

During World War II, Suess worked primarily on the chemistry of deuterium, potentially important for nuclear fission reactors, and made occasional trips as a scientific advisor to the heavy water plant at Vemork, Norway, which had been occupied by the Germans in 1940 and was destroyed by Allied bombs in 1943. During the war years, he also became interested in the structure of nuclei and origin of the elements, realizing the importance of "magic numbers" of protons and neutrons, which made the nuclides containing those numbers more abundant and more stable than their neighbors. Suess was associated with J. Hans D. Jensen (1907–1973) in formulating a shell model of the nucleus (analogous to the model of electron shells due to **Niels Bohr**), for which Jensen shared the 1963 Nobel Prize with Maria Goeppert Mayer, who had worked out the same structure independently.

Suess moved to the University of Chicago to work with Harold Urey in 1950 and went on to the United States Geological Survey in Washington State, USA, the next year. There he set up a laboratory to do carbon-14 dating of organic materials dating from roughly the past 50,000 years. Suess developed a new technique in which carbon samples were processed to gaseous acetylene for measurement, and used it to establish the chronology of the end of the last Ice Age in the Northern Hemisphere and to show that dilution of atmospheric carbon dioxide by the burning of fossil fuels could make samples look older than they really are. This is sometimes called the Suess effect.

Roger Revelle invited Suess to join the Scripps Institute of Oceanography at the University of California, San Diego, in 1955, where he established a new radiocarbon lab and served as professor of geochemistry from 1958 to1977. An important early result was the calibration of carbon-14 dates against accurate counts of annual rings in trunks of very old trees. Deviations of about 10% in either direction around the average correlation were initially dubbed Suess wiggles, but are now understood to reflect changes in the speed and density of the solar wind flowing past the Earth and, therefore, in the intensity of cosmic rays that can penetrate that wind to produce carbon-14 in the Earth's upper atmosphere, and which may affect the climate.

The paper on "Abundances of the Elements" by Suess and Urey came in 1956. It included not just elemental abundances but also the relative amounts of the various stable isotopes of each element (ten for tin, but beryllium only one). The abundance numbers for elements that readily form solids came primarily from certain classes of primitive meteorites, and the numbers for gases like hydrogen and nitrogen from the Sun. A current compilation of abundances shows remarkably few and remarkably small differences from their results.

During his years at San Diego, Suess acted as a consultant to the International Atomic Energy Agency in Vienna. Suess received his Dr. *Habilitation* from Hamburg in 1938, an honorary degree from Queen's University (Belfast), and awards from the Guggenheim Foundation, the Alexander von Humboldt Foundation, and the Geochemical Society. He was a member of the national academies of science of the United States and Austria.

Fathi Habashi

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Ṣūfī: Abū al-Ḥusayn ʿAbd al-Raḥmān ibn ʿUmar al-Ṣūfī

Born **Rayy (near Tehran, Iran), 903**
Died **986**

Ṣūfī spent his life as an astronomer in Iran, in close relation to the regional rulers of the Buyid dynasty. The most important of his several astronomical and other works was the *Book on the Constellations* (*circa* 964). In it he gave a description of the 48 Ptolemaic constellations, based on the Arabic translations of **Ptolemy**'s *Almagest*, with detailed critique for each of the 1,025 stars in Ptolemy's star catalog, based on his own observations. Two drawings of each constellation were added, one "as seen in the sky," and one "as seen on the (celestial) globe."

The book became very influential both in the Orient and in Europe. Its text and nomenclature were taken up by many later authors, such as the encyclopedist Qazwīnī (died: 1283) and the Timurid Prince and astronomer **Ulugh Beg** in the star catalog of his astronomical handbook (epoch: 1437). For centuries, Arabic–Islamic astronomers followed the forms of the constellation figures as drawn in Ṣūfī's book, in written works and on instruments (celestial globes).

In Europe, Ṣūfī's book was not among the many scientific Arabic works that were translated into Latin between the late 10th and the 13th centuries. Nevertheless, its contents became known there and exerted considerable influence in several instances. King **Alfonso X** of Castile (reigned: 1252–1284) had a free recension of the book, with constellation drawings, included in his multivolume astronomical handbook, *Libros del saber de astronomia*; an Italian translation of this appeared in 1341. Perhaps also in the 13th century, a text corpus was compiled in Sicily, where drawings of the 48 constellations from Ṣūfī's book were combined with Ptolemy's star catalog (in the Latin translation of **Gerard of Cremona** from the Arabic) and extracts from some other astronomical and astrological texts (the so called Ṣūfī Latinus corpus, of which eight manuscripts are known today). In 1515, two maps of the Northern and Southern Celestial Hemispheres were printed in Nuremberg after woodcuts made by **Albrecht Dürer**. One of four portraits of important astronomers added by Dürer to the map of the Northern Hemisphere is an imaginary portrait of Ṣūfī (here called Azophi, with a medieval Latin spelling). In the 1530s, the German astronomer **Peter Apian** somehow made use of Ṣūfī's book, mentioned some old Arabic asterisms, and even converted them into drawn constellation figures on a star map. Ṣūfī's stellar nomenclature – in Arabic script – was also used on a celestial globe by J. A. Colom (*circa* 1635) and on the "King's globe" (1681–1683) by V. Coronelli. In 1665, Thomas Hyde published in Oxford an edition of **Ulugh Beg**'s star catalog; in the accompanying commentary he amply quoted from Ṣūfī's book. From here, **Giuseppe Piazzi** picked up around 100 Arabic star names, which he added to the 1814 edition of his Palermo star catalog, thereby introducing them into modern astronomy. Ṣūfī's name (in its medieval Latinized form, Azophi) was given by **Giovanni Riccioli** (1651) to one of the craters on the Moon.

Paul Kunitzsch

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Sulaymān ibn ʿIṣma: Abū Dāwūd Sulaymān ibn ʿIṣma al-Samarqandī

Flourished **Samarqand, (Uzbekistan), second half of the 9th century**

Much of our information on Sulaymān ibn ʿIṣma comes from the remarks of **Bīrūnī**. According to Bīrūnī, Sulaymān made observations in Balkh (Afghanistan) in 888–890 for determining the obliquity of the ecliptic. For this purpose, he used a mural quadrant (*libna*) provided with an alidade, the diameter of the quadrant being about 8 cubits (*dhirāʿ*), approximately 4 m. He found the meridian solar altitude at the winter solstice to be 29° 46′ and at the summer solstice 76° 54′. From this he determined that the obliquity of the ecliptic was 23° 34′, 1 min less than the result of **Battānī**. Bīrūnī also tells us of Sulaymān's determination of the length of Spring and Summer, and attributes to Sulaymān a *zīj* (astronomical handbook) dealing with the Sun and Moon (*Zīj al-nayyirayn*), as well as a book on the construction of an instrument for determining the visibility of the crescent (*Qānūn* II, p. 654). **Nasawī** claims that Sulaymān also wrote a commentary on the *Almagest*.

Finally, Sulaymān composed a commentary on the tenth book of Euclid's *Elements*, which is still extant.

Giuseppe Bezza

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Sundman, Karl Frithiof

Born **Kaskinen, (Finland), 25 October 1873**
Died **Helsinki, Finland, 28 September 1949**

Karl Sundman is most widely remembered for his analytic solution to the so called three-body problem, and for his design of an analog computer, which was planned to perform the power series calculations needed for modeling planetary perturbations. He was the son of custom-house officer Johan Frithiof Sundman and Adolfina Fredrika Rosenqvist. His parents attempted to train him as a fisherman, but the boy was interested in academic learning, and prepared privately for admission to the Imperial Alexander-University at Helsinki. There, he studied mathematics and physical sciences (1893–1897) and also assisted in the bureau for stellar photography at the local astronomical observatory. From 1897 to 1899, Sundman studied at the Pulkovo Observatory, where he examined the orbital motions of the minor planets. His doctoral dissertation (1901) addressed the perturbations of minor planets having a mean motion twice that of Jupiter.

In 1902, Sundman was appointed *Privatdozent* (lecturer) in astronomy at Helsinki. He also conducted postdoctoral studies (1903–1906) in Germany and Paris, France. In 1907, Sundman was appointed extraordinary professor of astronomy, and in 1918 full professor and director of the Helsinki Observatory. He retired from that post in 1941.

During his directorship, the research program of the observatory (led by Ragnar Furuhjelm) concentrated on completion of the Helsinki Zone of the International *Carte du Ciel* Astrographic Chart and Catalogue begun by Sundman's predecessor, **Anders Donner**. Sundman accepted this responsibility as a matter of course, even though his own interests were directed toward celestial mechanics. Sundman was an unassuming scholar; he founded no school and had scarcely any followers who continued his work.

Sundman is best known for his theoretical solution to the three-body problem. Here, one considers three mass points having fixed masses, along with known initial positions and velocities, which attract one another according to Newton's law. The long history of the problem began with **Isaac Newton** himself. In 1772, **Joseph Lagrange** obtained five restricted solutions in closed form (Lagrangian points L1 through L5). By around 1890, it was generally accepted that a more complete solution must be sought in the form of a power series or expansion.

King Oscar II of Sweden offered a prize for the solution of some unsolved mathematical problems; one of them was the three-body problem. The prize was awarded in 1889 to **Jules Poincaré** for his pathbreaking study that initiated a new approach to celestial mechanics. Yet, Poincaré did not solve the problem posed. Within this context, Sundman began his own investigation, and he succeeded in providing a solution to the problem in two papers published by the Finnish Society of Sciences (1907, 1909). A more widely known summary was published in the journal *Acta Mathematica* (1912).

Sundman's work gave in principle an algorithm for calculating the power series representing the motions of the bodies. This algorithm, however, is so complicated that the series cannot in practice be used to compute the positions of the bodies or even to obtain a qualitative knowledge of their behaviors. Yet, the significance of Sundman's result arises from the fact that, after centuries of debate as to whether or not an analytic solution existed, he showed that it does exist for all initial values that provide a nonvanishing angular momentum to the system.

Sundman treated also the special case where the condition on the angular momentum is not fulfilled. In that case, a simultaneous collision of all three bodies becomes possible. The case of more than three bodies gives rise to complications that cannot be treated using Sundman's constructions.

Sundman's other works gave computationally more accessible treatments to the problem of perturbations. These included an article that he contributed to the *Encyclopädie der mathematischen Wissenschaften* (1915). Sundman also insisted that it was possible to construct a machine capable of performing (to a satisfactory approximation) the calculations needed for the perturbations. To achieve this end, he designed an analog computer and explained its principles in another 1915 paper. In his later years, he tried to realize these ideas, but his attempts came to naught. After the rise of digital electronic computers, Sundman's ideas retained only a historical value.

Sundman was in many respects a conservative scientist. He never accepted **Albert Einstein**'s general theory of relativity but speculated about nonrelativistic explanations for the anomalous perihelion advance of Mercury. This attitude was not uncommon among traditional astronomers of his generation.

Sundman was a member of the Finnish Society of Sciences, a foreign member of the Royal Swedish Academy of Sciences, and a member of the editorial board of the *Acta Mathematica*. His work concerning the three-body problem earned him the 1913 de Pontécoulant Prize of the French Academy of Sciences. Sundman married twice – first to Edith Rosa Maria Anderson, and then to Fanny Alexandra Janhunen. The couples had no children.

Raimo Lehti

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Suyūṭī: Abū al-Faḍl ʿAbd al-Raḥmān Jalāl al-Dīn al-Suyūṭī

Born **Cairo, (Egypt), 1445**
Died **1505**

Suyūṭī wrote an important work on "religious" astronomy, whose sources derived from the traditions of the Prophet. Born into a family engaged in religious scholarship and holding administrative offices, he became the most prolific authors in all of Islamic literature. His father was a preacher, taught Shāfiʿī religious law, and acted as a deputy judge (*qāḍī*). He died prematurely when his son was only 5 years old, but he had made financial arrangements that allowed Suyūṭī to pursue a path of scholarship through the guardianship and aid of his father's friends and students. Suyūṭī commenced his studies at an early age, with the study of Islamic religious sciences under various teachers. This included the study of *ḥadīth* (statements and actions of the Prophet Muḥammad and his companions as recorded by his contemporaries and collated into collections by later authors), some rudimentary arithmetic for the solution of problems of inheritance, and probably the study of rudimentary timekeeping (*mīqāt*) and traditional medicine. At the young age of 18, he assumed his father's former position of teaching religious law at the Shaykhū mosque and provided juridical consultative opinions. Soon afterward in 1467, Suyūṭī reinitiated the study of *ḥadīth* at the mosque of Ibn Ṭulūn. He was appointed to teach *ḥadīth* at the prestigious Shaykhūniyya *madrasa* (religious college) in 1472 and then was given a royal appointment by the Mamlūk Sultan Qā'it Bāy (reigned: 1468–1495) to the directorship of the Baybarsiyya *khānqāh* (Ṣūfī lodge) in 1486. Suyūṭī's personality and convictions resulted in controversy and polemics with contemporary scholars as well as officials among the ruling Mamluks. He withdrew from public life in 1501, following a conflict over the finances of the Baybarsiyya *khānqāh* and spent the rest of his days editing and revising his works.

Suyūṭī wrote over 500 works that primarily focus on topics and issues in the Islamic religious and the Arabic linguistic disciplines. Two of his works deal with astronomy and medicine. His interest in astronomy, however, was not in what we or his contemporaries would call scientific, *i. e.*, related to the pre-Islamic astronomical heritage that had been transmitted in the 8th and 9th centuries. Rather his interest in astronomy lay in the discussion of celestial objects and phenomena as found in the corpus of literature and activity, which comprises *ḥadīth*. As such, his *al-Hay'a al-saniyya fī al-hay'a al-sunniyya* (*The radiant cosmology: On sunnī cosmology*) is a religiously oriented account of "cosmology," that is to say, celestial and terrestrial entities from the perspective of *ḥadīth*, or more precisely the *ḥadīth* corpus which, in Suyūṭī's view, reflects the position of the Sunnī community as laid out by Sunnī religious scholars. In the introduction of the *Radiant Cosmology*, Suyūṭī states,

> "This is a book on cosmology (*ʿilm al-hay'a*), which I have compiled from the traditions (*al-athār*) and have appended it with reports [by earlier narrators] (*akhbār*) so that those with intelligence may find delight and those with vision may reflect. I have titled it *The Radiant Cosmology: On Sunnı Cosmology*."

On the one hand, Suyūṭī wanted to inform his readers about Sunnī cosmology, as it was discussed in traditions and reports of earlier narrators. On the other hand, Suyūṭī's choice of the term cosmology (*hay'a*) for his religious enterprise was novel. The astronomers had utilized the term *hay'a* since the 9th century to signify the configuration of the celestial orbs. Thus the term *ʿilm al-hay'a* was used to signify the discipline of "astronomy." Suyūṭī's appropriation of the terms *hay'a* and *ʿilm al-hay'a* for his enterprise indicates a conscious attempt to present an alternative religious cosmology, that is to say an "Islamic cosmology," to replace the "scientific" cosmology of the astronomers. In his *Autobiography*, Suyūṭī is quite explicit regarding his views on science:

> I do not occupy myself [with] logic and the philosophical disciplines (*ʿulūm al-falsafa*) because they are forbidden, and even if they were permissible, I would not prefer them to the religious disciplines.

During this period, astronomy, and other sciences, certainly fell under the classification of "philosophical disciplines." Suyūṭī and other religious scholars regarded them with suspicion for, in their view, these disciplines ultimately derived from pre-Islamic sources. Suyūṭī regarded his sources, in contrast, to be the unimpeachable views of religious scholars from earlier generations. Just as they had provided the material for the sound formulation of Islamic Law that governed all aspects of life, including the proper practice of rituals, the sound understanding of the text of the Qur'ān, and so forth, only they could provide the basis for a sound "Islamic" cosmology, that is to say the cosmology for Muslims who follow the path of tradition and orthodoxy (*i. e.*, the Sunnīs). He held similar views regarding medicine.

The subjects that Suyūṭī treats in the *Radiant Cosmology* comprise the Divine Throne (*ʿarsh*), the Divine Footstool (*kursī*), the Tablet (*lawḥ*), and the Pen (*qalam*), which are entities mentioned in the Qurʾān, as well as the seven heavens and seven Earths, Sun, Moon, stars, night, day, hours, water and winds, clouds and rain, thunder, lightning, thunderbolt, Milky Way, rainbow, earthquakes, mountains, seas, and River Nile. Suyūṭī's approach to these subjects is apparent in his chapter headings, which refer to reports of the views of selected earlier authorities regarding these "cosmological" entities. As such, the *Radiant Cosmology* preserves the views of these earlier religious authorities whose works are lost to us.

Alnoor Dhanani

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Swan, William

Born **Edinburgh, Scotland, 13 March 1818**
Died **Helensburgh, (Strathclyde), Scotland, 1 March 1894**

William Swan is perhaps best known for his pioneering identification of features due to carbon compounds in the spectra of comets now called Swan bands and seen in stars and other sources. From 1850 to 1852 he was mathematical master in the Free Church of Scotland Normal School, and in 1853 was appointed teacher of mathematics, natural philosophy, and navigation in the Scottish Naval and Military Academy. He pursued scientific studies and published papers in *The Philosophical Magazine*, among others. Swan served as professor of natural philosophy at the United College of Saint Andrews University, Scotland, from 1859 to 1880, retiring due to ill health.

Swan was said to have been inquisitive, witty, and intelligent, with a fierce intolerance of fraud; he once described a wooden clock as "ferociously coarse and useless." Like many of his Victorian contemporaries, Swan had multiple interests, enjoyed broad literary and musical friendships, was a deacon of his church, and remained perpetually curious. His work in spectroscopy was meticulous.

Swan performed significant work on the flame spectra of carbon and hydrocarbon compounds. He insisted on the need for very pure samples to ensure that analysis would be fruitful. He was also one of the first (1856) to use a collimator in his spectroscope, which significantly improved the efficiency of his instrument.

Swan first associated several bright emission features in the spectra of comets with identical emission bands observed in candle flames in 1857. The Swan bands originate from the carbon molecule C_2; three prominent emission heads occur at wavelengths of 5636, 5165, and 4737 Å. These are formed when sunlight excites diatomic carbon in the tail of a comet. The carbon then fluoresces and emits light at these discrete wavelengths. The Swan bands give the comet's gaseous (or ion) tail its characteristic blue–green color.

Swan's 1856 attempt to extend **Joseph von Fraunhofer**'s study of solar absorption lines to the spectra of stars was not successful. He was, however, able to observe the spectrum of Mars and remarked that its appearance was "more brilliant than I anticipated." He is also credited with invention of the Swan prism photometer, used for measuring the brightnesses of stars, and establishing that "red protuberances" (prominences) seen in total solar eclipses arise from the Sun and not the Moon. Swan additionally made important suggestions for the improvement of lighthouse lenses.

Swan compiled a detailed inventory of the scientific and historic instruments preserved in the Department of Natural Philosophy at Saint Andrews. Among the instruments from his catalog that still exist are an armillary sphere, a Gregorian telescope, and several astrolabes.

Swan was awarded the Gold Medal of the Royal Scottish Society of Arts for his work in spectroscopy in 1883. He was also the recipient of honorary LLDs from Edinburgh University (1869) and Saint Andrews University (1886), and was a member of the Royal Society of Edinburgh.

Portions of Swan's correspondence are preserved at the Saint Andrews University Library.

Katherine Haramundanis

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Swedenborg, Emanuel

Born **Stockholm, Sweden, 29 January 1688**
Died **London, England, 29 March 1772**

Best known for his religious writings, Emanuel Swedenborg was active as a scientist, engineer, statesman, and philosopher. In astronomy, he was the first to propose that the Solar System originated

from a swirling nebula. Swedenborg published treatises on nearly every scientific and philosophical issue of his age.

Upon graduation from the University of Uppsala, Swedenborg traveled abroad for 5 years, visiting England, Holland, France, and Germany, one of many such trips throughout his life. In 1710 he began studies in England. Swedenborg's studies might have ended before they began, as the impetuous young man was nearly hanged for breaking the plague quarantine of his vessel. He was an agent for his home university, with instructions to acquire whatever books and scientific instruments would improve its collection, and to make detailed reports about scientific ideas, techniques, and instruments.

Swedenborg met some of the leading intellectuals of the day. Astronomer Royal **John Flamsteed** inspired him to devise his own solution to the longitude problem. Swedenborg took careful notes about the instruments at Greenwich: His dream, never realized, was to establish an observatory in Sweden. Swedenborg became particularly close to **Edmond Halley**, who acquainted him with the problem of the lunar motion, and he spent several months in Oxford to be near his mentor. Although initially enthusiastic about Newtonianism, he found **Isaac Newton**'s reticence toward inquiring into the ultimate causes of phenomena (*hypotheses non fingo*) unsatisfying. In his *magnum opus*, also called *Principia* (1734), Swedenborg presents his own natural philosophy.

On his return home in 1715, Swedenborg launched Sweden's first scientific journal, *Daedalus Hyperboreus*, which featured new inventions, theories, and scientific discussion. He was appointed by the king as assessor to the Board of Mines, a position that he occupied (making substantial improvements to the mining industry) until his retirement in 1747. Swedenborg was active in research, sketching many inventions, (including a submarine, a flying machine, a new type of siphon, and an air pump) and making fruitful investigation into human perception and the brain. After 1747 he devoted the remainder of his life to religious writing.

While Swedenborg's contributions to neuroanatomy are better known, he also published astronomical and cosmological treatises. Two of these will be considered here: a solution to the longitude problem (1721), and a theory of the origin of the Solar System (1734).

Longitude determination was the outstanding practical issue of the time. The lunar distance method, proposed by **Johann Werner** in 1514, was in widespread use: It employs the Moon as a clock as it moves against the fixed stars. Werner's method was impractical at the time, since there existed neither sufficiently accurate star tables or instruments, nor a correct lunar theory. In 1714, the British Board of Longitude offered £20,000 for a practical and accurate method for reckoning longitude at sea. After extensive discussion with Flamsteed and Halley, Swedenborg published *Methodus nova inveniendi longitudines locorum terra marique ope lunae* (Amsterdam, 1721). The board rejected it, since his solution did not meet the requirements for the prize – he provided no tables for lunar and stellar positions. When compared to the 1765 prize-winning solution, which involved the combined efforts of several men including **Tobias Mayer**, Flamsteed, and **Leonhard Euler**, it is clear that Swedenborg's was not a complete solution.

Swedenborg's "nebular hypothesis" for the origin of the Solar System, described in his *Principia rerum naturalium* … (Dresden, 1734), anticipated the cosmological theories of **Georges Leclerc** (Comte de Buffon; 1749), **Immanuel Kant** (1775), and **Pierre de Laplace** (1796). Swedenborg's conception was derived from his philosophy of "like-partedness," the idea that every entity is recursively composed of smaller, homologous versions of itself, and that it likewise forms a component part of a larger entity. For the Solar System, Swedenborg proposed that the Sun had developed a dense surface layer that was forced outward by the centrifugal force of its rotation, into the equatorial plane of the solar rotation. Continuing its outward motion, this ring eventually thinned and broke apart into smaller bodies that formed the planets and smaller bodies. Swedenborg's theory, unlike those of Buffon, Kant, and Laplace, is primarily based on an *a priori* conception rather than empirical investigation.

Glen M. Cooper

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Swift, Lewis

Born **Clarkson, New York, USA, 29 February 1820**
Died **Marathon, New York, USA, 5 January 1913**

Lewis Swift discovered 13 comets and 1,248 previously uncataloged nebulae, which placed him after only **William Herschel** in the number of nebulae he discovered visually. His report of the hypothetical planet Vulcan was eventually discredited.

The son of Lewis and Ann (*née* Forbes) Swift, the younger Lewis was born into a distinguished family. His father was a general in the local militia, while his grandfather had served in the Revolutionary War in general Putnam's personal guard. An earlier ancestor had emigrated from England to Massachusetts in 1630. Swift's father farmed, and during the winter made farming implements; as a young man Swift also showed mechanical ingenuity. His life was changed when, at age 13, he fractured his hip during a farming accident and was unable to continue his work on the family farm. Instead – incapacitated for farm work – young Swift gained time for study. He trudged the 2 miles to the local school on crutches and laid the rudiments of his education. That same year (1983) he was awestruck by the great Leonid meteor storm, and 2 years later by the apparition of comet 1P/Halley. For a decade or more after completing the schooling available to him in Clarkson, Swift traveled as an itinerant science lecturer.

After his marriage in 1850 to Lucretia Hunt, Swift became a country storekeeper at Hunt's Corner, New York. Like **Edward Barnard**, he was stimulated in his incipient astronomical interest by reading the works of **Thomas Dick** and fashioned a 3-in. Spencer lens into a first small telescope. Inspired by the dramatic orations of **Ormsby Mitchel** in nearby Rochester during 1857 and 1858, when the Spencer lens was accidentally broken, Swift replaced that primitive first telescope with a 4½-in. Henry Fitz refractor. Two years later, Swift discovered his first comet, which had also been discovered independently by **Horace Tuttle** at Harvard College. The comet, 109P/1862 O1 (Swift–Tuttle) proved to be periodic; it returns to perihelion once every 134 years. Later in the 1860s, the Italian astronomer **Giovanni Schiaparelli** showed that comet 109P/Swift–Tuttle left debris in its orbit, which the Earth encounters each year as the Perseid meteor shower – the famous August meteors.

After Lucretia died in 1862, Swift married Caroline Topping of Long Island, New York, in 1864; they had one son, Edward. In 1872, Swift moved to Rochester, New York, to open a hardware store. From the flat roof above a nearby cider mill where he set up his telescope, Swift began discovering comets with considerable regularity. He found new comets in 1877 (C/1877 G2), 1878 (C/1878 N1), and 1879 (C/1879 M1), receiving Gold Medals from the Vienna Observatory for each of these discoveries.

One of Swift's most famous observations occurred during the total solar eclipse of 1878. From his observing station at Denver, Colorado, Swift reported observing Vulcan, a hypothetical planet between the Sun and Mercury. Vulcan had been postulated by the French mathematical astronomer **Urbain Le Verrier** to explain the advance of Mercury's perihelion. Swift's observations were taken seriously at the time, in part because University of Michigan astronomer **James Watson** also reported observing Vulcan from his eclipse site near Rawlins, Wyoming. Vulcan remained a controversial subject among astronomers for four decades. In 1916, **Albert Einstein** published his general theory of relativity, which satisfactorily accounted for the motions of Mercury for which Vulcan had been invoked as a cause.

Swift's work attracted the interest of Hulbert Harrington Warner, a patent-medicine vendor whose *Safe Remedy* promoted good bowel hygiene, a late-Victorian obsession. Warner endowed an observatory at the corner of East Avenue and Arnold Park in Rochester. The Warner Observatory was equipped, with public donations, with a 16-in. Clark refractor, then the fourth largest in the United States. Swift was placed in charge of the observatory. He gave public demonstrations of the telescope, served as clearinghouse for claims to Warner's prize for new comet discoveries, and charted new nebulae – most of them now known to be galaxies. The latter turned up by the hundreds in areas of the sky like Draco, which was located far from the Milky Way. Neither Swift nor anyone else knew what the nebulae were; they remained shrouded in mystery, and, as he told a meeting of the American Academy for the Advancement of Science in 1884, "this is, and for ages to come must be, true." However, Swift and others, notably **Stéphane Javelle** of France, were discovering so many new nebulae that **Johann Dreyer** abandoned his efforts to update his New General Catalogue and started the Index Catalogue to accommodate the new discoveries.

Swift found conditions in upstate New York – the snowbelt – less than ideal for observing; most portraits of him show him wearing a woolen cap. With city electrification, the skies over Rochester became less and less favorable. Swift managed to discover a new comet in 1892 (C/1892 E1), which became the brightest since 1883; it brightened to 3rd magnitude, and its intricate tail was captured in wide-angle photographs taken at Lick Observatory by **Edward Emerson Barnard**. After his business failed in the financial panic of 1893, Warner abandoned Rochester and moved to Minnesota, where he retired to an obscure old age.

With no support in Rochester, and after considering a number of offers, Swift joined Civil War balloonist and businessman Thadeus Sobieski Constantine Lowe (1832–1913) in setting up an observatory built around the 16-in. refractor at Echo Mountain, in California's Sierra Madre range. At the Lowe Observatory, Swift – dubbed the "Columbus of the Skies" by residents of nearby Pasadena and now in his 70s – continued to discover uncataloged nebulae. He discovered his last comet, his 13th, in 1899 (C/1899 E1), when he was almost 80. His son, Edward, also discovered a comet at the Lowe Observatory in 1894 (C/1894 W1).

The Lowe Observatory narrowly escaped a wildfire in 1900. By then Swift's eyesight was beginning to fail. At last in 1904 – even as **George Hale** arrived in California to develop the new Mount Wilson Observatory on another mountain, 3,000 ft. higher in the Sierra Madres – Swift retired, and returned to upstate New York to live in obscurity with his daughter. He died, all but forgotten by earlier generations of astronomers, among whom he had once been prominent. In his own words: "So much for fame!"

Swift was elected a fellow of the Royal Astronomical Society [RAS] and received an honorary Ph.D. from the University of Rochester in 1879. The French Academy of Sciences awarded Swift their Lalande Silver Medal and Prize in 1881, while the RAS selected him to be the first recipient of their Jackson-Gwilt Medal and Gift in 1897.

William Sheehan

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Swings, Polydore [Pol] Ferdinand Felix

Born **Ransart, Belgium, 24 September 1906**
Died **Eseneux, Belgium, 28 October 1983**

Belgian spectroscopist Polydore Swings codiscovered the first interstellar molecule and identified a number of other molecules and radicals in the spectra of nebulae and comets. He was educated at the prestigious Athénée Charleroi, where an early interest in astronomy was stirred by the books of **Camille Flammarion**, and studied celestial mechanics under Marcel Dehalu at the University of Liège, earning a first degree in 1927. Swings spent the next 2 years in France, taking courses at the Sorbonne, the Collège de France, and the Institute d'Optique and working at the Observatoire de Paris in Meudon, where he learned the techniques of astronomical spectroscopy.

Swings returned to Liège in 1928 and, apart from brief visits abroad, spent the rest of his academic career there. Delahu and he set up a laboratory to carry out spectroscopy, since the wavelengths to be expected from many molecules (neutral and ionized) were not known or calculable at the time. He investigated the molecule S_2 on a visit to the Institut de Physique at Warsaw University, receiving a second degree from Liège in 1931 for this work. Swings focused on the phenomena of predissociation (in which a molecule is excited to a state with more energy than is required to unbind it) and fluorescence (in which an atom or molecule is excited by ultraviolet light in a line or continuum and emits a specific wavelength of visible light as it cascades back to its ground state), which he applied to a number of astronomical contexts over the years.

In 1931, Swings began a collaboration with **Otto Struve** observing and interpreting stellar and nebular spectra, and pushing the available data into ultraviolet wavelengths using the new quartz spectrograph at the (also new) McDonald Observatory. That collaboration became closer when the Swings family came to the United States for a sabbatical in 1939, remaining for the duration because Germany soon occupied Belgium. Pol and Christiane Swings's son Jean-Pierre, also an astronomer and eventually general secretary of the International Astronomical Union, was born in the USA. They spent time at Yerkes, McDonald, and Lick observatories, and Swings built spectrographs for the United States Navy at Lick. The most cited work by Struve and Swings dates from this period. They were able to interpret the spectra of stars with very extended envelopes, like P Cygni, in terms of absorption in the stellar photosphere plus emission from the extended gas, with the strengths of some lines greatly enhanced by fluorescence when the gas was moving at just the right velocity to have, for instance, a strong line of hydrogen or helium fall at the wavelength needed to excite some particular state. They also determined the expansion velocities of nova explosions, and showed that the hottest gas expanded most slowly.

In 1937, Swings and Leon Rosenfeld (1904–1974, a younger associate of **Niels Bohr**) identified a sharp 4303.3 Å astronomical line observed by **Theordore Dunham** that same year with a laboratory transition of the CH molecule. Since the line is a "stationary" one (*i. e.*, its wavelength does not shift back and forth with the stellar lines in the spectra of binary stars), it must be produced by gas that is not associated with the stars themselves. Swings and Rosenfeld therefore added a molecular component to the interstellar atomic gas discovered in 1904 by **Johannes Hartmann**.

During and after the war, Swings turned his attention increasingly to the study of cometary spectra, for which ultraviolet spectra are particularly important. He and **Andrew McKellar** found that a spectral feature at 4050 Å that they had seen in stars with carbon-rich atmospheres was also present in many comets, and they suggested it might be produced by a carbon molecule of more than two atoms, then a radical idea in astronomy. They were vindicated when German–Canadian spectroscopist **Gerhard Herzberg** and others identified C_3 or carbazone molecular features with the ones, now called the Swings band, in the stars and comets. Swings and his colleagues, first in the United States and later back in Belgium, gradually added CH^+, OH^+, CO_2^+, CN, CH, OH, and NH_2 to the cometary inventory and concluded that most of these must come from stable "parent" molecules of H_2O, CO_2, NH_3, and CH_4 in the ices of cometary nuclei. A 1956 Atlas of Representative Cometary Spectra summarized this work and long remained a standard. The name Swings effect is given to the fluorescence of ultraviolet CN features whose intensity changes as comets move toward and away from the Sun and Doppler shifts swing particular transitions in and out of resonance with the exciting solar line.

Swings established a long-running series of summer conferences at Liège, whose published proceedings were authoritative sources on stellar astronomy for many years. He was president of the International Astronomical Union from 1964 to 1967 and was one of about a dozen European astronomers who actively collaborated to establish the European Space Research Organization (now European Space Agency) and the European Southern Observatory. Swings received the highest Belgian scientific honor, the Prix Franqui, and the Royal Academy of Belgium now awards a prize in his and his wife's names to a promising young astrophysicist every 4 years.

Peter Wlasuk

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Swope, Henrietta Hill

Born **Saint Louis, Missouri, USA, 26 October 1902**
Died **Pasadena, California, USA, 24 November 1980**

American variable star astronomer Henrietta Swope is remembered for the discovery and period determinations of a very large number of RR Lyrae, Cepheid, and other variables, the later ones on plates taken by **Walter Baade**.

Swope was the daughter of Gerard Swope (president of General Electric and director of the National Broadcasting Company) and Mary Dayton Hill. She became interested in astronomy while attending lectures by Margaret Harwood at Maria Mitchell Observatory on Nantucket, Massachusetts, and received a BA from Barnard College (Columbia) in 1925 and an MA from Radcliffe College (Harvard) in 1928.

Swope was appointed to an assistantship (partly financed by her father) at Harvard College Observatory in 1928 to continue her work with **Harlow Shapley** on galactic variable stars. Her work was of great precision; of 35 periods for RR Lyrae stars that she published in one 1929 paper, 34 remain definitive, and she worked on about 1,600 variables between 1927 and 1942. Her father's money also permitted the hiring of an assistant for her, **Dorrit Hoffleit**.

With the outbreak of World War II, Swope moved to the radiation laboratory at the Massachusetts Institute of Technology, where she helped to develop LORAN navigation tables with Fletcher G. Watson (1912–1997), and then in 1943 to the hydrographic office of the United States Department of the Navy, where she remained as a mathematician until 1947.

Her non-reappointment at Harvard after the war led to a position, first, as associate astronomer at Barnard College and Columbia (1947–1952), and then as assistant astronomer at Mount Wilson and Palomar observatories (1962–1967), where Swope was first Baade's assistant, and, after his death, his scientific executor. She completed the work on Cepheid variables that led to a new determination of the distance to the Andromeda Nebula (M31) of 2.2 million light years or 675,000 parsecs in 1962, very close to the best modern value. For several years, in the early 1960s, Swope appeared in the annual official photographs of the Mount Wilson–Palomar scientific staff, the only woman to do so in roughly the first 80 years of the observatories' existence. She held the title research fellow from her retirement in 1967 until shortly before her death.

Swope received the Annie J. Cannon Award of the American Astronomical Society in 1968 (the last one given as a lifetime achievement award) and is eponymized *via* the minor planet (2168) Swope. Her gift to the Carnegie Institution of Washington (former owners of Mount Wilson Observatory) made possible the initial development of the Las Campanas Observatory in Chile and the establishment of the first 40-in. Swope telescope there, though she herself never observed at either Mount Wilson or Palomar Mountain, under the policies then in force.

Katherine Haramundanis

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Synesius of Cyrene

Born **Cyrene (near Darnah, Libya), *circa* 365–370**
Died **Ptolemaïs (near Al Marj, Libya), *circa* 413**

Synesius of Cyrene figured prominently in the literary, philosophical, scientific, and religious culture of the Greek east of Late Antiquity, playing a leading role on the contemporary political and historical stage. He also wrote a description of an astrolabe and encouraged the study of the heavens in order to know the divine.

Synesius's birth date remains conjectural. He spent his youth in Cyrenaica, receiving a classically grounded education typical of the landed aristocracy. Sometime after 390 he began the study of philosophy, mathematics, and the sciences in Alexandria with the Neoplatonist **Hypatia**, with whom he maintained close personal contact throughout his life. After several years in Alexandria, Synesius returned home, but soon traveled to Constantinople on diplomatic business on behalf of his province.

Synesius remained in the imperial capital until 402. While involved in the affairs of the court of Emperor Arcadius, he may have begun his association with Christianity. He later married a Christian and settled again in Cyrenaica, although he visited Alexandria a number of times in subsequent years, continuing his contact with Hypatia and others in her intellectual circle. Little is known about Synesius's other activities until 410, when he was appointed Bishop of Ptolemaïs, a post he held until his death around 413.

Synesius represents the blending of pagan Hellenism with the burgeoning Christian culture of late Roman times. Moreover, his wide range of interests, from the purely intellectual and practical to the mystical and even the magical, is evidence of the intellectual landscape of his day. Synesius's substantial extant written corpus consists of poems, hymns, homilies, and a variety of essays on philosophy and politics. In addition, a large collection of letters gives an especially intimate portrait of Synesius's life, of his intellectual pursuits, and of his relationship with his contemporaries, especially Hypatia.

A number of Synesius's works touch upon astronomical matters and cosmology. In some of the hymns (most notably nos. three and four) appears the Neoplatonist belief that the visible and invisible Universe is in itself divine, and several passages praise the beauty and majesty of the cosmos. Along with other philosophical topics, this same mystical engagement with the heavens appears in Synesius's letter to Paeonius (*Ad Paeonium de dono*, *circa* 397/398) that accompanied the gift of a silver astrolabe. To prompt in that imperial official an appreciation for astronomy, Synesius says that a knowledge of the divine is attainable through the study and practice of observing the skies. He also includes an epigram of **Ptolemy** that expresses a deep reverence for the visible Universe and his own verse composition on the benefits of using the instrument.

Additionally, though somewhat confused and at times vague, his technical description of the astrolabe itself, which Synesius calls only the *organon* ("instrument"), constitutes a contribution to its history and to an understanding of the general astronomical knowledge of the day. For example, Synesius famously ascribes to **Hipparchus** a knowledge of the astrolabe and assertes that Ptolemy had used such a device to determine the hours of the night. He also credits his teacher Hypatia with instructing him how to construct the instrument and claims that he himself had added the final details to perfect it, saying that he wrote a (now lost) treatise on the topic. He discusses actual design features of the object, including the placement of the celestial circles and the number of stars shown. Synesius also seems to have represented the celestial sphere as projected onto a shallow concave surface, thereby modifying a true astrolabe's stereographic projection of the celestial dome onto a flat plane.

Nevertheless, Synesius does not seem actually to have contributed anything to the theory or design of the astrolabe itself. In fact, his instrument may actually have been a kind of a celestial map incorporating only some features of an astrolabe.

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T

Ṭabarī: Abū Jaʿfar Muḥammad ibn Ayyūb al-Ḥāsib al-Ṭabarī

Flourished **(Iran), 1092–1108**

Ṭabari lived in Iran under the Saljūqs, probably in Āmul, and is the author of two independent treatises in Persian on the astrolabe as well as several other books, including two on arithmetic. Although several modern studies place him in the 13th century, he must have lived earlier based upon manuscript sources and since he is mentioned by al-Bayhaqī in his *Tatimmat ṣiwān al-ḥikma* (1164).

The first astrolabe treatise is known under the title *Shish faṣl* (Six chapters [on the knowledge of the astrolabe]), the oldest manuscript copy dating to 1176–1177. It was probably composed at the request of some students and is arranged in a question–answer (q/a) format:

(1) On the parts of the astrolabe and their names (60 q/a);
(2) On lines, figures, inscriptions, and circles on the astrolabe (77 q/a);
(3) On knowing the functioning of the back part of the astrolabe (49 q/a);
(4) On knowing the functioning of the face side of the astrolabe (136 q/a);
(5) On knowing how to check the exactness of the astrolabe (28 q/a);
(6) On the use of the astrolabe for land-surveying/measuring (*misāḥa*) (17 q/a).

The second treatise is a shorter and simplified version of the "six chapters" and is arranged simply into 104 entries. Entitled *ʿAmal wa-alqāb* ([On the] functions and names [of the astrolabe]), the oldest extant manuscript copy is dated 1162. It was written for a certain nobleman of his time, who is named in two copies as Abū al-Fatḥ Dawlatshāh ibn Sulaymān. In the beginning of the treatise, Ṭabari states that there are three types of astrolabes: (1) spherical (*kurī)* used in earlier times; (2) circular (*dawrī*), used in the time of the author, who describes it as circular and flat; and (3) boat-shaped/*navicula* (King, 1999, p. 352) (*zawraqī*), which is nevertheless described by Ṭabari as a "hemisphere, like a cup," who indicates that it was used in pre-Islamic Iran and that the astrolabe was called in Pahlavi "the cup that mirrors the world" (*jām-i jahān-namā*). This passage is not found in **Abū Rayḥān al-Bīrūnī's** *Tafhīm* and is quoted here as a curiosity.Ṭabarī's two treatises on the astrolabe are among the oldest extant Persian texts on the subject. For a detailed study of their content, they should be compared to the earlier chapter on the astrolabe in Bīrūnī's *Tafhīm* and to the later *Bist bāb dar maʿrifat-i usṭurlāb* (20 chapters on knowledge on the astrolabe) by **Naṣīr al-Dīn al-Ṭūsī**.

Živa Vesel

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Tacchini, Pietro

Born **Modena, (Italy), 21 March 1838**
Died **Spilamberto, (Emilia-Romagna), Italy, 24 March 1905**

Astrophysicist, meteorologist, and seismologist, Pietro Tacchini distinguished himself as one of the fathers of solar astrophysics, inventor of one of the first sunspot classifications, editor of the oldest astrophysics review, first observer of the details of Venus' atmosphere spectrum, deviser of the first experiments of synchronization of astronomical observations, and organizer of scientific projects and institutions, both national and international.

Born the son of Bartolomeo Tacchini and Giuseppina Selmi, Pietro graduated *cum laude* in engineering during autumn 1857 at the Modena Archiginnasio. Tacchini was noticed for his talent by **Giuseppe Bianchi**, director of the Modena Observatory, who wanted to make him a good assistant. To allow him to learn astronomy, in April 1858, Bianchi (thanks to a scholarship bestowed by the Duke of Modena) sent Tacchini to the Padua Observatory where he served his apprenticeship under the guidance of **Giovanni Santini** and Virgilio Trettenero. In September 1859, Tacchini was designated *ad interim* director of Modena Observatory by the dictator Luigi Carlo Farini. Tacchini thus succeeded Bianchi who had suddenly resigned for political reasons. During his time in Modena, Tacchini continued the astronomical observations and corresponded with **Giovanni Schiaparelli**, director of the Brera Observatory, and **Angelo Secchi,** S.J., director of the Collegio Romano Observatory.

In 1863, following Schiaparelli's advice, Tacchini became assistant astronomer of the Palermo Observatory. After designing the refractor room and mounting, in 1865, the Merz equatorial 25-cm telescope (requested by Domenico Ragona to substitute for the Troughton used by **Giuseppe Piazzi**), Tacchini did his principal studies on solar meteorology consisting of a series of observations of solar photosphere and chromosphere, especially the faculae, prominences, and sunspots. He proposed classifications for these phenomena in 1871. (His sunspot classifications were based on connections with terrestrial magnetism.) Thanks to these studies, Palermo became one of the capitals of solar astrophysics. Tacchini was also one of the principal observers of southern stars and of seven among the most important contemporary solar eclipses. One of these was on 22 December 1870; its totality path passed through Sicily. Another was in 1883, which he observed from the Caroline Islands; this observation permitted Tacchini to note the calcium white prominences, different from the hydrogen red ones. In these years, together with Secchi, Arminio Nobile, and Emanuele Fergola, he made the first experiments in synchronization of astronomical observations of the solar limb by using a telegraph. (With Nobile, Tacchini measured the difference in longitude between Palermo and Naples.)

His success in solar spectroscopy and the need to monitor solar activity led Tacchini to found, in 1871 with Secchi and **Lorenzo Respighi**, the Società degli Spettroscopisti Italiani, the oldest professional society specifically devoted to astrophysics. Among its members were Nobile and **Giuseppe Lorenzoni**. From 1872 onward, Tacchini, as president of the Society, launched in Palermo the publication of its official journal, the *Memorie della Società degli Spettroscopisti Italiani* (now *Memorie della Società Astronomica Italiana*), an internationally distributed review that is considered the oldest one on astrophysics still in print.

In 1874, Tacchini was asked to organize the Italian astronomical expedition to Muddapur, India, to observe the passage of Venus across the solar disk on 8/9 December. The expedition, organized by Tacchini, Alessandro Dorna, and **Antonio Abetti**, observed, for the first time, the details of Venus's spectrum (**Joseph von Fraunhofer**'s lines C and B), thus confirming the existence of an atmosphere. The expedition also validated the use of spectroscopic observations to determine the exact instant of limb contact. During the trip to India, needing a low latitude observatory for winter solar observations, Tacchini founded the spectroscopic Calcutta Astronomical Observatory, at Saint Xavier College (directed by Eugène Lafont, S.J.)

From 1874 on, Tacchini, in order to reorganize astronomical research in Italy, promoted a reform project for astronomical observatories, accepted by the Italian government in 1876. He proposed to divide them into three classes: true astronomical observatories (in Florence, Naples, Milan, and Palermo), university observatories, and meteorological observatories.

In 1879, after Secchi's death, Tacchini was called to Rome as director of the Collegio Romano Observatory. In Rome, Tacchini also directed the new R. Ufficio Centrale di Meteorologia (and di Geodinamica, from 1887).

In 1880, the Bellini Observatory was founded. Promoted by Tacchini, it sat at a high altitude (2,940 m) on the Etna volcano to reduce atmospheric effects. It was equipped with a Merz 33-cm refractor. Despite the ideal altitude, ash emissions from the volcano hindered long-duration observations, forcing Tacchini to found the downtown Catania Astrophysical Observatory, financed by the government. This was necessary in order to be able to participate in the *Carte du Ciel* international enterprise promoted by the French Academy of Sciences and lasting more than 50 years. (This observatory was the only Italian participant.)

In 1890, at Catania, Tacchini helped found the first Italian astrophysics chair, assigned to **Annibale Riccò**, director of the Palermo Observatory.

In 1893, Tacchini was invited to the World Congress on Astronomy and Astro-Physics by **George Hale** who saw in him a master of organization. They collaborated to publish the *Astrophysical Journal*, from 1895, of which Tacchini was an associate editor.

Tacchini's work in astrophysics earned him the Rumford Medal of the London Royal Society in 1888 and the Prix Janssen of the Paris Académie des sciences in 1892. He was a fellow of the Accademia dei Lincei and of the Accademia Nazionale delle Scienze, and a foreign member of the Royal Astronomical Society and of the Royal Society.

Leonardo Gariboldi

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Tadahide

Nishikawa, Joken

Takahashi, Yoshitoki

Born **Osaka, Japan, 1764**
Died **Asakusa, Edo (Tokyo), Japan, 1804**

Yoshitoki Takahashi was a leading scholar and advocate of calendrical reform in Japanese Edo culture, based on the importation of Western scientific methods. His father, Tokujiro Takahashi, was a lower-class official in Osaka. Considered a prodigy, the young Takahashi developed an early interest in mathematics. In 1779, he took up his father's profession and pursued intellectual interests in his spare time. Even if a man was of poor means in Edo Japan (1603–1867), he could still advance in social status if he had intellectual talent. Takahashi certainly had such talent, and he began to study with the noted calendar scholar **Goryu Asada** around 1787.

Takahashi found common interests with the wealthy merchant and instrument maker Shigetomi Hazama, who was also a student of Asada. They developed a long relationship of mixed cordiality and rivalry. With encouragement from Asada, Takahashi continued his work in mathematics and observational techniques related to the construction of an accurate lunar calendar. The work of Asada and his students came at a time when information about advances in Europe only trickled into Japan. Teachers and students at the Asada School studied the *Li-shiang K'ao-ch'eng Hou-pien* (a Sequel to the Compendium of Calendrical Science and Astronomy), edited by Ignatius Kögler, that included **Johannes Kepler**'s theory of elliptical orbits and **Jean-Dominique Cassini**'s work on the motions of the Sun and Moon. While the young student did not understand the full implications of celestial mechanics contained within the work, Takahashi found particularly fertile ground in its mathematics and empirically verifiable concepts.

As theoretical ideas matured, the Asada School developed a reputation that received notice from the *Tokugawa* shogunate in Edo. Seeing the accuracy gained by using advanced techniques, the shogunate felt it necessary to reform the current *Horyaku Reki* calendar. Asada was asked to join the calendar reform project but, on account of illness, he recommended Takahashi and Hazama instead. Both went to Edo, and Takahashi was assigned to the Tenmongata (Bureau of Astronomy) in 1795. Plans for calendar reform were completed in 1797, and a new calendar, called *Kansei Reki*, was officially placed into operation in 1798.

An accurate lunar calendar is dependent upon precise determinations of terrestrial latitudes and longitudes. Takahashi felt that accurate locations of Japanese cities should be acquired with the increased precision of astronomical instruments. Assisted by his own student, **Tadataka Ino**, a national survey under Takahashi's guidance (with the aid of Hazama) was conducted. This effort culminated in a large collection of maps of Japan used well into the 20th century.

Many have considered Takahashi to be a consummate theorist, but in an atmosphere of abject pragmatism, his gifts certainly found their most significant outlet in the development of more accurate methods of calendar construction. Working with secondary sources pertaining to western scientific developments, and not always understanding the full implications of such reports, he was able to adapt and apply modern methods to his own efforts in ingenious ways. For example, Takahashi was able to calculate the length of the tropical year and the synodic month within several decimal places of their currently accepted values.

Takahashi unhesitatingly tackled ideas from the west and even worked out an epicyclic theory for trepidation, misguided as the concept was. He began a translation from a Dutch version of **Joseph de Lalande**'s *Traité d'Astronomie* and compiled a multivolume work, entitled *Rarande Rekisho Kanken* (A Review of Lalande's *Astronomie*). Unable to finish the full translation, the work was completed by his second son. Takahashi was a prime influence in Ino's work related to precision measurements of latitude and longitude. Along with Asada, Takahashi was perhaps most influential in showing the viability of using western astronomical methods for calculating the movements of celestial bodies at a time of officially sanctioned superstition and indifference. At the time of his death, he was trying to develop rigorous techniques for accurately calculating planetary movements along with predictions of lunar and solar eclipses.

When Takahashi passed away, his eldest son, Kageyasu, succeeded him in the Bureau of Astronomy. The noted Shibukawa family later adopted his second son, Kagesuke. Both men continued in their father's footsteps.

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Tang-Jo-Wang

➜ **Schall von Bell, Johann Adam**

Taqī al-Dīn Abū Bakr Muḥammad ibn Zayn al-Dīn Maˁrūf al-Dimashqī al-Ḥanafī

Born **Damascus, (Syria), 14 June 1526**
Died **Istanbul, (Turkey), 1585**

Taqī al-Dīn was the founder and the director of the Istanbul Observatory and worked in the fields of mathematics, astronomy, optics, and mechanics. He made various astronomical instruments and was the first astronomer to use an automatic–mechanical clock for his astronomical observations. He advanced the arithmetic of decimal fractions and used them in the calculation of astronomical tables.

Taqī al-Din began his studies, as was normal, with the basic religious sciences and Arabic. Later on, he continued his religious studies and studied the mathematical sciences with scholars in Damascus and Egypt, including most significantly his father. It is probable that Taqī al-Dīn's teacher in mathematics was Shihāb al-Dīn al-Ghazzī whereas the one in astronomy was **Muḥammad ibn Abī al-Fatḥ al-Ṣūfī**. Taqī al-Dīn himself states in several of the forewords to his books that he was particularly interested in the mathematical sciences during his education.

Taqī al-Dīn, after completing his education, taught for a short while at various *madrasas* (schools) in Damascus. He, together with his father Maˁrūf Afandī, came to Istanbul around the year 1550 where he benefited from his association with a number of prominent scholars. Taqī al-Dīn would shortly return to Egypt where he spent most of the next 20 years. A brief trip back to Istanbul, also around 1550, brought him into the company of the Grand Vizier Samīz ˁAlī Pasha, who allowed him to use his private library and clock collection. Taqī al-Dīn would benefit from this association when ˁAlī Pasha was appointed governor of Egypt, where he held positions as a teacher and judge (*qāḍī*) in Egypt. Encouraged to deal with mathematics and astronomy by a grandson of **ˁAlī Qūshjī**, who collected and gave Taqī al-Dīn works by his grandfather, by **Jamshīd al-Kāshī**, and by **Qāḍīzāde**, as well as various observation instruments, Taqī al-Dīn undertook a serious pursuit of astronomy and mathematics. While a judge in Tinnīn, Egypt, he made astronomical observations by means of an astronomical instrument that he mounted in a well that was 25-m deep.

Taqī al-Dīn returned to Istanbul in 1570 and was appointed head astronomer (*Müneccimbası*) by Sultan Selīm II upon the death of **Muṣṭafā ibn ˁAlī al-Muwaqqit** in 1571. He continued his observations in a building situated on a height overlooking Tophane or in Galata Tower and gained the support of several high officials. This led to an imperial edict by Sultan Murad III in early 1579 to build an observatory, which was located on a height overlooking Tophane where the French palace is located today. Important astronomical books and instruments were collected there. Little is known about the size, shape, and so on, but we do have magnificent depictions of the scholars at work and of the astronomical instruments in use (in *Ālāt-i raṣadiyya li-Zij-i Shāhinshāhiyya* [Istanbul Univesity, TY, MS 1993] and in ˁAlā' al-Dīn Manṣūr al-Shīrāzī's *Shāhinshahnāme* [Istanbul University, TY, MS 1404]). Apart from the observatory building, we hear of a well called *çah-i raṣad* that was also used by Taqī al-Dīn. Unfortunately the observatory did not last long. Due to political reasons, as well as Taqī al-Dīn's incorrect astrological prognostications, it was demolished by the state on 22 January 1580.

Taqī al-Dīn's most important work in astronomy is entitled *Sidrat muntahā al-afkār fī malakūt al-falak al-dawwār* (= *al-Zīj al-Shāhinshāhī*). This work was prepared according to the results of the observations in Egypt and Istanbul in order to correct and complete *Zīj-i Ulugh Beg*, a project originally conceived in Egypt and furthered by the building of the Istanbul Observatory. In the first 40 pages of the work, Taqī al-Dīn deals with trigonometric calculation. This is followed by discussions of astronomical clocks, heavenly circles, and so forth. In the following parts, he treats observational instruments and their use, the observations of lunar and solar motions, and trigonometric functions calculated according to sexagesimal. As was normal in the Islamic astronomical tradition, Taqī al-Dīn used trigonometric functions such as sine, cosine, tangent, and cotangent rather than chords. Following the work done at the Samarqand Observatory, he developed a new method to find the exact value of sin 1°, which Jamshīd al-Kāshī had put into the form of an equation of third degree. Additionally, Taqī al-Dīn employed the method of "three observation points," which he was the first to use for calculating solar parameters; apparently **Tycho Brahe** was aware of his work. For determining the longitudes and latitudes of the fixed stars, he used Venus, Aldebaran, and α Virginis (Spica), which are near the ecliptic (rather than the Moon), as reference stars. As a result of his observations, he found the eccentricity of the Sun to be 2° 0′ and the annual motion of apogee 63″. Taqī al-Dīn's values turn out to be more precise than those of **Nicolaus Copernicus** and Brahe. This provides evidence for the precision of Taqī al-Dīn's methods of observation and calculation. It is thus a pity that the destruction of the observatory meant that Taqī al-Dīn was unable to complete his observation program. Indeed in the absence of a conclusion to this *Zīj*, it can probably be concluded that the book was never completed.

Taqī al-Dīn's second most important work on astronomy is a *zīj* entitled *Jarīdat al-durar wa kharīdat al-fikar*. In this work, for the first time we find the use of decimal fractions in trigonometric functions. He also prepared tangent and cotangent tables. Moreover, in this *zīj*, as in another of his *zīj*es entitled *Tashīl zīj al-aˁshāriyya al-shāhinshāhiyya*, Taqī al-Dīn gave the parts of degree of curves and angles in decimal fractions and carried out the calculations accordingly. Excluding the table of fixed stars, all the astronomical tables in this *zīj* were prepared using decimal fractions.

In addition, Taqī al-Dīn has some other astronomical works of secondary importance. One of them is *Dustūr al-tarjīḥ li-qawāʿid al-tasṭīḥ*, which is about the projection of a sphere onto a plane as well as other topics in geometry. Another of his works is *Rayḥānat al-rūḥ fī rasm al-sāʿāt ʿalā mustawī al-suṭūḥ*, which deals with sundials drawn on marble surfaces and their features. This book was commented upon by his student Sirāj al-Dīn ʿUmar ibn Muḥammad al-Fāriskūrī (died: 1610) under the title *Nafḥ al-fuyūḥ bi-sharḥ rayḥānat al-rūḥ*; the commentary was translated into Turkish by an unknown writer in the beginning of the 17th century.

In addition to his 20 books on astronomy, Taqī al-Dīn wrote one book on medicine and zoology, three on physics-mechanics, and five on mathematics. He has a monograph entitled *Risāla fī ʿamal al-mīzān al-ṭabīʿī* on the specific gravity of substances and **Archimedes**' hydrostatic experiments. All of his books are in Arabic.

Taqī al-Dīn's works on physics and mechanics, besides being interesting in their own right, also have connections with astronomy. In 1559 while in Nablus, he wrote his *al-Kawākib al-durriyya fī waḍʿ al-bankāmāt al-dawriyya*, which dealt with mechanical-automatic clocks for the first time in the Islamic and Ottoman world. In the foreword, Taqī al-Dīn mentions that he benefited from using Samiz ʿAlī Pasha's private library and his collection of European mechanical clocks. In this work, Taqī al-Dīn discusses various mechanical clocks from a geometrical–mechanical perspective. His second book on mechanics is the one he wrote when he was 26, *al-Ṭuruq al-saniyya fī al-ālāt al-rūḥāniyya*. In this work, Taqī al-Dīn focuses on the geometrical-mechanical structure of clocks previously examined by the **Banū Mūsā** and Abū al-ʿIzz al-Jazarī. In the field of physics and optics, Taqī al-Dīn wrote *Nawr ḥadīqat al-abṣar wa-nūr ḥaqīqat al-Anẓar*, which dealt with the structure of light, its diffusion and global refraction, and the relation between light and color.

In his mathematical treatises, Taqī al-Dīn dealt with various aspects of trigonometry, geometry, algebra, and arithmetic. In the latter, he carried on the work of Kāshī in developing the arithmetic of decimal fractions both theoretically and practically.

Taqī al-Dīn was a successor to the great school of Samarqand and, following the lead of ʿAlī Qūshjī, tended toward a more purely mathematical approach in his scientific work that was beginning to abandon Aristotelian physics and metaphysics. Taqī al-Din's most significant achievement in the history of Islamic and Ottoman astronomy is his foundation of the Istanbul Observatory and his activities there. Besides using established instruments and techniques, he developed a number of new ones as well, including his use of the automatic–mechanical clock. Carrying on the work of his Islamic predecessors, Taqī al-Dīn's application of decimal fractions to trigonometry and astronomy stands as another important contribution to astronomy and mathematics.

İhsan Fazlıoğlu

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Tarde, Jean

Born **La Roque-Gageac near Sarlat, (Dordogne), France, 1561 or 1562**
Died **Sarlat, (Dordogne), France, 1636**

Jean Tarde was an early French Copernican and student of sunspots. The social status of Tarde's family is uncertain, although probably bourgeois. At his death, Tarde left behind a considerable estate, and his family remained in high positions in the bourgeois community. Tarde received his doctorate in law from the University of Cahors and then continued his studies at the University of Paris. He was ordained a priest and assigned to the parish of Carves, near Belvès. Soon after, he was promoted to canon theologian of Sarlat's cathedral. The bishop of Sarlat, Louis de Salignac, wishing to ascertain the effects of France's religious wars on the diocese, appointed Tarde as vicar general in 1594, commissioning him to map out the diocese. In 1599, Henri IV appointed him an *almoner* (royal chaplain), for which Tarde received a pension.

Tarde mapped out the neighboring diocese at the request of the bishop of Cahors in 1606, employing a quadrant fitted with a compass needle and attached to a sundial. The bishop's interest in the quadrant prompted Tarde to publish *Les usages du quadrant à l'esguille aymantée* (1621), dedicated to the bishop. His cartographic work demonstrated his interest in geometry, drawing, drafting, and the practical uses of instruments – skills he found useful in his astronomical work.

In November 1614, Tarde visited **Galileo Galilei** in Florence (his second of two trips to Italy). According to Tarde's diary, he flattered Galilei and told him that he had read his *Siderius nuncius*, and wanted to know the latest observations made by the famed Italian. Galilei told him about several observations including his sighting of two stars (the rings) around Saturn, the phases of Venus, and the spots on the face of the Sun, remarking that since others using telescopes had also seen these spots, they could not be illusions. Galilei also told him that the spots took 14 days to move across the Sun's face and that their movements were similar to those of Mercury and Venus. When Tarde asked Galilei how to build a telescope, Galilei claimed he did not know how it worked and instead referred Tarde to **Johannes Kepler**'s book on optics, promising also to send him a lens in Rome. While Tarde never received the lens, he did visit with Galilei twice more before returning to France in February of 1615.

After his return, Tarde established an observatory to observe sunspots, an activity he pursued for 5 years. Based on his previous conversations with Galilei and his own observations, Tarde published his *Borbonia sidera* in 1620. In 1622 he published and dedicated to Louis XIII a French translation entitled *Les astres de Borbon*, with which was bound Tarde's theoretical work on the telescope, *Telescopium, seu demonstrationes opticae*.… In *Les astres de Borbon*, Tarde defended the validity of telescopic data and described his own instrument for observing the Sun – a *caverne obscure* (*camera obscura*), the device invented by **Christoph Scheiner**, in which a telescope projected the image of the Sun onto a white surface in a darkened room.

Tarde rejected (as had Scheiner and Galilei) the notion that sunspots were illusions or that they were located within the Earth's atmosphere, claiming also that they were not spots on the Sun or comets. He concluded that sunspots were distinct bodies (planets, or as he called them, *étoiles errantes*) that orbited the Sun, and, following Galilei's precedent with the satellites of Jupiter, he named them the Bourbon stars after the French royal family. Tarde's theory was based on his firm belief that the Sun was the seat of God and could not be blemished or tarnished. Although he criticized the Aristotelians, Tarde did not break entirely free from that tradition and was determined to fit the new observational data into his own framework. In his discussions of the Sun, Tarde also addressed heliocentrism. Citing **Pythagoras** and **Nicolaus Copernicus**, he argued in favor of heliocentrism, indicating that it was an easier and more convenient system as far as astronomical calculations were concerned. But Tarde did not fully commit himself to heliocentrism either because of the church's prohibition of Copernicanism or because heliocentrism had not been proven yet.

Galilei raised several objections to Tarde's theory of *étoiles errantes* that the latter refuted. The one point that Tarde conceded to Galilei was retrograde motion – the spots on the Sun do not exhibit retrograde motion as the superior planets do. To address this argument, Tarde complained that the weather had interfered with his observations and that, in any case, retrograde motion was too difficult to detect for these "planets" in any case, because of their proximity to the Sun. **Pierre Gassendi** also criticized Tarde's theory in a 1625 letter to Galilei, claiming that the lack of a periodic return of the "planets" was proof that they were not circling the Sun. However, in 1633, Gassendi wrote to **Nicolas de Peiresc** that he was still waiting for more evidence in support of Tarde's theory that might persuade him more fully. The dispute faded away soon after Tarde's death.

In the mid-19th century, **Urbain Le Verrier** argued that his calculations indicated that there was a planet between the orbit of Mercury and the Sun. This led to a revival of interest in Tarde, whose work was scrutinized (including by one of Tarde's descendants, Gabriel Tarde) to find evidence in support of Le Verrier's theory. This attempt failed, however, when Le Verrier's theory was proven false. Nevertheless, late-19th-century interest in Tarde's work motivated Gabriel Tarde and Gaston de Gérard to publish in 1887 Tarde's unpublished history of Sarlat, *Les Chroniques de Jean Tarde*.

Voula Saridakis

Alternate name

Tardeus

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Tardeus

➜ **Tarde, Jean**

Taylor, Geoffrey Ingram

Born **Saint John's Wood, (London), England, 7 March 1886**
Died **Cambridge, England, 27 June 1975**

Geoffrey Ingram Taylor is recognized within astronomy for the description of Taylor columns (rotating, rising fluid structures, of which the Great Red Spot on Jupiter may be an example) and for development of the theory of the Rayleigh–Taylor instability, in which a dense fluid, held up by the pressure of a less dense one underneath, rather suddenly exchanges positions with the less dense fluid, in a swirl of eddies and fingers. Supernova explosions and a range of other astronomical events and sources show evidence of the phenomenon. His work also has found applications in meteorology, oceanography, engineering, and aeronautics.

Taylor's father was Edward Ingram Taylor. His mother was Margaret (*née* Boole) Taylor, daughter of George Boole, the mathematician. Taylor grew up in an atmosphere conducive to an appreciation of science under the influence of his parents and the other Boole daughters, respected scientists in their own right. Indeed, at the age of 12, he and a friend constructed an X-ray generator, only 2 years after Röntgen had first discovered the ray's existence. Taylor's mechanical skills and ingenuity were also on display as a teenager, when he managed not only to build a sailboat in his bedroom, but also to get it out of his window and sail it on the Thames. Starting in 1905, Taylor attended Trinity College at Cambridge, studying mathematics and physics. Upon graduation, he received a scholarship for postgraduate research, and worked with J. J. Thomson on the interference of low-intensity beams of photons. This led to his first published paper, in 1909. (The last appeared in 1973.) Taylor remained at Cambridge for most of his career, latterly as a fellow of Trinity College and a Royal Society Professor at the Cavendish Laboratory.

Taylor quickly shifted his interest from pure physics to fluid mechanics, and his second published paper, in 1910, studied the structure of shock waves and garnered him a Smith's Prize at Cambridge. In 1911, he received a readership in dynamical meteorology and delved into an analysis of small-scale processes, including momentum and heat transfer in response to turbulent fluctuations. Taylor found that turbulent velocity distributions were isotopic except near the ground, in contrast to prevailing theory of the time. In response to the sinking of the Titanic, the British government sponsored a study of the distribution of icebergs in the North Atlantic in 1913, and Taylor was named meteorologist of the research ship, *Scotia*. This allowed him to study transfer properties on a much larger scale. His analysis of the results put forward the concept of a mixing length for turbulent diffusion.

Taylor was also very interested in stability of turbulent systems, including his famous work on steady flow between concentric circular cylinders. He investigated the motion of objects in a rotating liquid. He discovered that where Coriolis effects are dominant, Taylor columns form, of which the Red Spot of Jupiter is considered to be a potential example. Taylor subsequently published several phenomenological papers on turbulence, culminating in the 1930s with an empirically testable understanding of the statistical properties of turbulence and a determination of the energy spectrum of turbulent motion.

Taylor was always interested in practical problems, and was active in war research in World War I and World War II. During the former, he studied shafts under torsion to build better airplane propeller shafts. In the latter, he worked on the Manhattan Project on shock waves and saw the first nuclear explosion at Alamogordo. Even after his retirement in 1951, and for the next 20 years, Taylor continued to investigate new problems in fluid mechanics, including how small organisms swim, electrohydrodynamics, and dynamics of thin sheets of liquid. Several other important discoveries in physics of fluids and solids bear his name, including the Taylor–Proudman theorem (one of whose consequences is that rotation of a fluid inhibits convection), Taylor–Couette instabilities, Taylor dislocations (in crystals, a topic he worked on intermittently from 1934 onward), and the Taylor dispersion relation (describing the relationship between frequency and wavelength in unstable, incompressible flows). It might seem surprising that his work on the behavior of a fluid trapped between a solid cylinder and the inside of a cylindrical chamber is still commonly cited. It is because there remain even now surprisingly few exact results in the description of convective energy transport in fluids.

Taylor was famous both for his ability to find the important problems to work on and for his ingenuity in finding simple and elegant experiments to test his predictions. Among his honors were fellowships in the Royal Society, the United States National Academy of Sciences, and the American Philosophical Society, knighthood in 1944, and admission to the United Kingdom Order of Merit in 1969. George Batchelor and Sir Brian Pippard, both from Cambridge, were among Taylor's scientific heirs.

Michael Fosmire

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Tebbutt, John

Born **Windsor, New South Wales, (Australia), 25 May 1834**
Died **Windsor, New South Wales, Australia, 29 November 1916**

During the last 3 decades of the 19th century, John Tebbutt became Australia's leading astronomer, amateur or professional, and made valuable meteorological contributions. Although he was offered the Sydney Observatory directorship in 1862, he decided to remain an amateur astronomer and successfully combined astronomy and farming for the rest of his life.

The son of John and Virginia (*née* Saunders) Tebbutt, the younger John attended local church schools where he excelled academically. At age 15, he began working full-time on his father's farm on the outskirts of Windsor; he inherited the farm in 1870. On 8 September 1857, Tebbutt married Jane Pendergast; they had one son and six daughters.

Tebbutt was largely self-taught as an astronomer. During the 1850s he used his naked eye, a marine telescope, and a sextant to observe sunspots, aurorae, meteors, lunar eclipses and occultations, Jupiter's satellites, comets, and the variable star Algol. Tebbutt taught himself the mathematics required to compute comet orbits, and began publishing astronomical reports in the Sydney newspapers.

On 13 May 1861, Tebbutt detected a faint nebulous object in Eridanus. Comet C/1861 J1, or the Great Comet of 1861, developed into one of the most magnificent comets of the century, featuring a tail more than 100° in length at its prime. This discovery inspired Tebbutt to purchase an 8.3-cm Jones refractor. In 1863, he constructed a simple observatory that eventually housed this refractor, a 5.3-cm transit telescope from Sydney scientific instrumentmaker, Angelo Tornaghi, and a chronometer. Tornaghi also made a ring micrometer for the refractor. A full set of meteorological instruments completed the observatory's instrumentation. Over the years, Tebbutt arranged the construction of three new Windsor Observatory buildings (1874, 1879, and 1894) and the addition of 11.4-cm Cooke and 20.3-cm Grubb equatorial refractors and a 7.6-cm Cooke transit telescope. New micrometers and chronometers also were acquired.

Although the Windsor Observatory was modest by international standards, Tebbutt more than compensated for this with his dedication and enthusiasm. Between 1863 and his semiretirement in 1903, Tebbutt conducted an amazing range of observational programs. He continued intermittent observations up to 1915.

Comets were without doubt Tebbutt's favorite observational targets. Between 1853 and 1912 he observed 50 different periodic and nonperiodic comets. He obtained micrometric positions for many of these comets on every possible clear night. Tebbutt's longest series of observations (103 nights) for any one comet was on C/1898 L1 (Coddington–Pauly). Tebbutt observed comet 2P/Encke on eight different returns and is credited with its recovery on three occasions. He also searched successfully for new comets, discovering two great comets, C/1861 J1 (the first comet for which astronomers, including Tebbutt, forecast the passage of the Earth through the tail), and C/1881 K1, from which important advances in astrophysical knowledge of comets were gained.

Tebbutt made important contributions to variable-star astronomy, including a detailed light-curve of η Carinae between 1854 and 1898 that revealed its minor outburst of the 1880s. His observations of the Mira type variable R Carinae from 1880 to 1898 allowed a precise determination of its period. He discovered Nova V728 Scorpii in 1862.

Tebbutt successfully observed the 1874 transit of Venus, but overcast skies prevented him from recording the 1882 event. In addition, between 1866 and 1899, he observed four transits of Mercury, six partial solar eclipses, and five lunar eclipses. Between 1877 and 1915, Tebbutt made many micrometric measures of 133 different double stars, and recorded accurate positions of 23 different asteroids. His measures of asteroids and comets were prized by orbit computers as they were frequently either the earliest or the last measures available for an apparition. Through Tebbutt's painstaking lunar occultation work, the Windsor Observatory became one of Australia's fundamental geodetic reference points.

Tebbutt maintained a time service for Windsor and operated a meteorological station. He provided Sydney Observatory with monthly weather reports from 1863 through to 1898 when a curtailed meteorological program was adopted. (These continued up to the time of his death.) Tebbutt supplied Sydney and Windsor-district newspapers with meteorological data on a regular basis.

Almost single-handedly Tebbutt carried out the time-consuming reduction of his astronomical and meteorological observations, and communicated his results to colleagues through Australian and international journals. In all he wrote two books and 323 different papers, some of which appeared in more than one journal. His *Annual Reports* of the Windsor Observatory were produced as booklets from 1888 to 1903 (inclusive). Tebbutt wrote two chapters for books by other authors, eight meteorological monographs, a number of booklets on the relationship between astronomy and religion, and hundreds of newspaper articles to popularize astronomy, a phenomenal output for a one-man observatory.

Tebbutt was a member of the Philosophical (later the Royal) Society of New South Wales from 1861 (and a stalwart of its short-lived Astronomy Section) and a fellow of the Royal Astronomical Society [RAS] from 1873. When the New South Wales Branch of the British Astronomical Association was founded in 1895, Tebbutt was elected its inaugural president.

Although an amateur, Tebbutt quickly gained an international reputation as an astronomer, and from 1869 his Windsor Observatory was included in the *Nautical Almanac's* listing of world observatories. In 1867 the government presented him with a silver medal, and in 1905 he was awarded the Jackson-Gwilt Medal and Gift by the RAS. In 1973 the International Astronomical Union arranged for lunar crater Picard G to be renamed Tebbutt. In 1984 Tebbutt's portrait was featured on a new Australian $100 bank note. Two surviving Windsor Observatory buildings were refurbished as a museum of astronomy in 1989 by his grandson, John Halley Tebbutt.

Tebbutt's status as Australia's leading astronomer led eventually to a bitter feud with Sydney Observatory director, **Henry Chamberlain Russell** that only ended in 1907 with Russell's death. Despite modest equipment, Tebbutt was able to make valuable contributions to observational astronomy. He played an important role in the development of Australian astronomical groups and societies and, more than any other 19th-century Australian astronomer, helped popularize astronomy. Tebbutt was a remarkable scientist, running what Joseph Ashbrook has likened to "1/4 a one-man Greenwich Observatory in the Southern Hemisphere."

Wayne Orchiston

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Teller, Edward [Ede]

Born **Budapest, (Hungary), 15 January 1908**
Died **Palo Alto, California, USA, 9 September 2003**

Hungarian–American nuclear physicist Edward Teller collaborated with **George Gamow** in studying the rules for beta decay and applications of astrophysics to controlled thermonuclear reactions.

Teller was the son of Miksa Teller and Ilona Deutsch. His marriage to Augustzta Maria Harkanyi produced three children – Paul, Susan, and Wendy, the last of whom is coauthor with him of an autobiography.

Teller studied at the Institute of Technology in Karlsruhe, Germany (1926–1928) and earned a Ph.D. in physics at the University of Leipzig in 1930. He was a teacher and researcher in various universities (Leipzig: 1929–1931; Göttingen: 1931–1933; Copenhagen: 1934 [where he first met Gamow at the Neils Bohr Instutute]; and London, 1934/1935); then in 1935 he emigrated to the United States where he became a naturalized American citizen in 1941. Teller was professor of physics at various universities: first George Washington (at the time of his collaboration with Gamov), 1935–1941; Columbia, 1941–1942; Chicago, 1946–1952; and California, 1953–1975. He also held office in various research institutions: Los Alamos National Laboratory, assistant director, 1949–1952; University of California, Radiation Laboratory, staff member, 1952–1953; Lawrence Livermore Radiation Laboratory, associate director then director, 1954–1975; and the Hoover Institute for the Study of War, Revolution, and Peace, Stanford University, senior researcher, 1975–2003.

Teller was *honoris causa* doctor of more than a dozen universities including Yale (1954) and George Washington (1960). He was recipient of the Joseph Priestley Memorial Award (1957), Albert Einstein Award (1958), Research Institute of America Living History Award (1958), Thomas E. White Award (1962), Enrico Fermi Award (1962), Robins Prize (1963), Arvey Prize (1975), and the United States Presidential Medal of Freedom (2003). He was a member of the American Academy of Arts and Sciences and honorary member of the Hungarian Academy of Sciences (1990).

Teller retained some interest in astrophysics even after issues of war and politics dominated his life. In 1949, Teller wrote with Maria Goeppert Mayer (Nobel Prize in Physics in 1963 for formulation of the nuclear shell model) on the possibility of accounting for the abundances of the elements in the Universe in terms of the fragmentation of an enormous mass of neutrons.

In 1939 Teller and fellow Hungarian physicist Leo Szilárd convinced **Albert Einstein** to join them in writing a letter to US president Franklin Roosevelt on the necessity to develop American nuclear weapons. Teller worked on the Manhattan Project, a military program for constructing an atomic bomb for wartime use. He was the first to study thermonuclear reactions in connection with weapons. After completion of the atomic bomb, his scientific interest turned to the more powerful fusion bomb. In the University of California's Livermore Radiation Laboratory, he worked on the hydrogen bomb. In 1954 Teller testified against his former Los Alamos colleague **Julius Robert Oppenheimer** who opposed the production of the hydrogen bomb and was accused of being a communist sympathizer.

Teller made major contributions to spectroscopy of polyatomic molecules and the theory of atomic nucleus. He is the author (or coauthor) of over a dozen books, mostly dealing with the problems of nuclear energy and defense.

László Szabados

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Tempel, Ernst Wilhelm Leberecht

Born **Nieder-kunnersdorf, (Sachsen, Germany), 4 December 1821**
Died **Arcetri near Florence, Italy, 16 March 1889**

Comet and asteroid seeker Ernst Tempel grew up on the parental farm and was intended for that occupation. With the support of a local schoolmaster, early on he taught himself drawing and gained knowledge of the sky. Tempel spent time as an apprentice for a lithographer in Dresden. He then spent 3 years in Copenhagen, Denmark, practicing this craft. Around 1850, Tempel went to Italy and in the employ of scientists prepared especially fine botanical drawings.

In 1856, Tempel worked for several months in Marseilles, France, at the observatory directed by Jean Valz. Similarly, he spent a short term in Italy assisting at the Bologna Observatory of **Lorenzo Respighi**.

In 1858, Tempel lived in Venice from where his wife, Marianna Gambini, came. The practical experience from Marseilles and Bologna in celestial observations sparked in Tempel the wish to possess a telescope. He acquired a 108-cm refractor from Munich, which enabled magnifications of 24, 40, and 300×. With it in 1859 he discovered comet C/1859 G1 (Tempel). He also confirmed the existence of nebulosity about the Pleiades (the Merope Nebula).

Tempel returned in 1860 to Marseilles. Valz had offered him a formal position as an assistant. There Tempel discovered minor planet (64) Angelina in 1861 and, four days later, minor planet (65) Cybele. For both of these discoveries, he received the Lalande Prize of the French Academy of Sciences.

Tempel observed jointly with Valz the 18 July 1860 total solar eclipse, in southern Spain. But after Valz's retirement in September 1861, Tempel left the observatory, as he found Valz's successor (Charles Simon, formerly mathematics teacher at the secondary school in Algiers) to be professionally incompetent.

Tempel worked again as a lithographer and returned to being an amateur astronomer. At his private observatory on the rue de Pythagore, Marseilles, he found further asteroids between 1861 and 1868 for a total of five.

Yet Tempel was dedicated to finding comets. Altogether he would discover 21 new comets and recover eight others. As a "comet hunter," Tempel can be considered the peer of the likes of **Jean Pons**, **William Brooks**, or **Edward Barnard.**

In the progress of the 1871 Franco-Prussian War, Tempel was expelled from France and went to Milan, Italy. There, as a respected amateur, he was engaged by **Giovanni Schiaparelli** at the Brera Observatory. Tempel continued his comet discoveries and very detailed drawings of celestial bodies.

After the death of **Giovani Donati**, Schiaparelli recommended Tempel as his successor, and so Tempel became director of the Arcetri Observatory in Florence. Here he found insufficient equipment. However, Tempel was accustomed to working under simple conditions and was able to use the opportunity to make additional discoveries. Most notable among these was the modern codiscovery of the Great Red Spot on Jupiter.

Minor Planet 3808 is named Tempel.

Jürgen Hamel

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Tennant, James Francis

Born **Calcutta, (India), 10 January 1829**
Died **London, England, 6 March 1915**

After observing the 1874 transit of Venus from India, British Army officer James Tennant became an authority on the notorious Black Drop effect. Tennant and **John Herschel, Jr.** (also in India) had previously observed the 1868 total solar eclipse, using spectroscopes.

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Terby, François Joseph Charles

Born **Louvain, Belgium, 8 August 1846**
Died **Louvain, Belgium, 20 March 1911**

François Terby was an important contributor to visual studies of Mars and Jupiter as well as to the history of those observations.

The son of music professor François Pierre Terby, François Joseph was educated at the Collège de Josephites in Louvain, and later at the University of Louvain, receiving degrees in philosophy, letters, and a Ph.D. in natural sciences. For several years he taught at the University of Louvain, and at the Collège Communal, and then as a professor of physics, chemistry, and mechanics at the École Industrielle, both also in Louvain. In about 1871, Terby gave up teaching to pursue observational astronomy as a full-time avocation in his private observatory.

Terby observed with a 3½-in. Secretan refractor, and after 1885 with an 8-in. Grubb equatorial refractor, concentrating on the planets, with especially noteworthy results on both Mars and Jupiter. He had begun observing Mars in 1864 and continued his observations of the red planet throughout his life. In addition to observing Mars, Terby decided to collect and discuss all prior observations of that planet in one volume. In the course of his effort to collect the observations, Terby performed a valuable service in tracking down the papers of **Johann Schröter,** which he preserved from loss by recovering them from one of Schröter's nephews. Terby wrote a memoir on Schröter's *Aerographische Fragmente* and on the Mars observations by every other known observer of Mars back to the 1636 observations of **Francisco Fontana** in his *Aérographie*, a valuable compendium published in 1875. Terby was awarded a prize by the Brussels Academy for that effort. Unfortunately, in his own observations, Terby succumbed to the all too common fate of Mars observers in that period. After **Giovanni Schiaparelli** published his observations of *canali* (canals) on the red planet, Terby looked for using Schiaparelli's map and imagined that he found them.

On Jupiter, Terby was among the first observers to record the appearance of the Red Spot, though his recognition of its uniqueness in his drawing was only retrospective after the announcement of its discovery by **Carr Pritchett**. By 1876, Terby was recognized well enough for his Jovian work that the Royal Astronomical Society appointed him to the first committee ever organized to systematically study Jupiter. That committee included **William Huggins**, **Edward Knobel**, James Ludovic Lindsay (Lord Lindsay, 1847–1913), **Wilhelm Lohse**, **William Parsons** (Third Earl of Rosse), **Arthur Ranyard,** and **Thomas Webb.**

Venus, and Saturn also attracted Terby's observational attention. Moreover he recorded many observations of meteors, comets, and the aurorae, and studied the lunar rills.

Terby was honored by election to the Royal Academy of Belgium in 1891, and as an officer of the Order of Leopold in 1907.

Thomas R. Williams

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Terrentius

➔ **Schreck, Johann**

Terrenz, Jean

➔ **Schreck, Johann**

Tezkireci Köse Ibrāhīm

Flourished **Szigetvár, (Hungary), 17th century**

Tezkireci, an Ottoman astronomer and bureaucrat who settled in Istanbul, is known for having translated the French astronomer Noel Durret's (died: *circa* 1650) work entitled *Nouvelle théorie des planètes* from French into Arabic; this was the first book in Ottoman scientific literature to have been translated from a European language. The work, which was printed in Paris in 1635, was translated sometime between 1660 and 1664 and appeared under the title *Sajanjal al-aflāk fī ghāyat al-idrāk* (The mirror of the orbs with the utmost perception). In addition to containing astronomical tables, it was the first work in the Ottoman world to discuss the Copernican system and **Tycho Brahe**'s model of the Universe. The book also included the first diagrams illustrating those systems.

A bureaucrat charged with writing official memoranda, Tezkireci found the time to occupy himself with astronomy. There is little other information about his life except what we can discern from his translated book. In the introduction, Tezkireci reports that when he first showed the translated work to the chief astronomer *(başmüneccim)* Müneccimek Şekîbî Mehmed Çelebi (died: 1667) in Istanbul, Müneccimek at first disapproved saying that "Europeans have many vanities similar to this one." But eventually Müneccimek came to appreciate the work after Tezkireci Köse prepared an ephemeris based on the French tables, and Müneccimek saw that it was in conformity with **Ulugh Beg**'s *Zīj* (astronomical handbook with tables). Müneccimek copied the work for himself and bestowed upon the translator a benefaction, saying, "You saved me from suspicion. Now I have full confidence in our *zīj*es."

In 1663 Tezkireci Köse again worked on the translation during his time with the Ottoman army at the winter quarters in Belgrade, this time with the encouragement of the *Kâdîasker* (chief judge) Ünsî Efendi (died: 1664). Tezkireci recalculated all the solar, lunar, and planetary mean motions of the *zīj* (originally compiled according to the meridian of Paris) and used the sexagesimal system; Tezkireci further abbreviated the tables and arranged them according to the signs of the zodiac *(abrāj)*. He presented a copy of the work to *Kâdîasker* Ünsî Efendi.

Later, Tezkireci Köse would translate most of the introduction of the work from Arabic into Turkish, leaving a few explanations in Arabic. This became the final form of the work. In the introduction, after a brief account of the history of astronomy, Tezkireci presents explanations, arranged in 24 subchapters *(taʿlīm)*, which are followed by tables. In 1683, Cezmî Efendi (died: 1692), a judge in Belgrade, found a copy of the *Sajanjal* that had probably been given to Ünsî Efendi, and prepared another edition of the work.

From the introduction to the *Sajanjal*, we learn from Tezkireci that he had written another work about which he states: "For the proofs I compiled a different and new treatise (*risāla)*, containing all operations that are easier [to use] than the *Almagest*, as well as compiled a work for ephemerides that are used internationally and that are more graceful and succinct than all [others]" (Istanbul, Kandilli Observatory Library, MS 403, fol. 2a).

Mustafa Kaçar

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Thābit ibn Qurra

Born **near Ḥarrān, upper Mesopotamia, (Turkey), *circa* 830**
Died **Baghdad, (Iraq), 18 February 901**

As a member of the **Banū Mūsā** circle of scholars in 9th-century Baghdad, Thābit ibn Qurra contributed significantly to the development of astronomy and other sciences through his translations and commentaries of Greek and Hellenistic works and through his original treatises. Notable astronomical contributions include a translation of **Ptolemy**'s *Almagest* and treatises on the motion of the Sun and the Moon. More generally, Thābit's significance lies in the influence of his work on the development of the exact sciences in Islam.

Thābit was a member of the Sabian religious sect. His heritage was steeped in traditions of Hellenistic culture and pagan veneration of the stars. This background, and in particular, his knowledge of Greek and Arabic, made him an attractive prospect for inclusion in one particular community of scholars – the Banū Mūsā and their circle in Baghdad. Thābit seems to have been asked to join this circle by a family member, the mathematician **Muḥammad ibn Mūsā ibn Shākir,** who recognized his talents and potential.

Thābit remained mainly in Baghdad, becoming a noted translator, physician, and renowned scholar in a variety of disciplines. As in the case of his mentors and teachers, Thābit was part of a family tradition of scholarly activity, with son Sinān ibn Thābit and grandson **Ibrāhīm ibn Sinān Thābit ibn Qurra** also making contributions to medicine and the exact sciences.

Thābit is credited with dozens of treatises, covering a wide range of fields and topics. While some were written in his native Syriac, most were composed in Arabic. Thabit was trilingual, a skill that enabled him to play a key role in the translation movement of 9th-century Baghdad. He translated works from both Syriac and Greek into Arabic, creating Arabic versions of important Hellenistic and Greek writings. Several of Thābit's Arabic translations are the only extant versions of important ancient works.

A large percentage of Thābit's corpus is devoted to mathematics. This includes translations of Books V–VII of **Apollonius**'s *On Conics* and **Archimedes**' *Lemmata* and *On Triangles*. His work in mathematics also includes original treatises, with contributions in the many areas of geometry and number theory. His original contributions include proofs of the Pythagorean theorem, a proof of Menelaus's theorem, proofs of Euclid's fifth postulate, and work on composite ratios.

Thābit's achievements in astronomy are closely linked to his work in mathematics. The application of his mathematical work (*e. g.*, his theories of composite ratios) to the examination and development of Ptolemaic astronomy, as Morelon emphasizes, helped establish a tradition of mathematical astronomy in Islamic culture. Discussion of Thābit's ideas is found in the work of later astronomers, including **Khāzinī** and **Naṣīr al-Dīn al-Ṭūsī**.

Thābit's revision of **Ḥunayn ibn Isḥāq**'s translation of the *Almagest* survives in manuscript. In addition, something less than a dozen astronomical treatises by Thābit have survived, about a fourth of the number he is credited with composing. Two of these present the basics of Ptolemaic astronomy, including the structure of the cosmos according to Ptolemy's *Planetary Hypotheses*, a work whose Arabic translation Thābit revised. In the other extant treatises, Thābit addresses the problem of the unequal motion of the Sun, the motion of the Moon, the determination of crescent visibility, and the theory of sundials.

Two treatises traditionally attributed to Thābit are almost certainly not by him. One of these that survives only in Latin translation is *De motu octave spere* (On the motion of the eighth sphere); the misattribution may be due to the fact that a related treatise was written by his grandson Ibrāhīm Ibn Sinān. The author of *De motu* addresses a type of problem that astronomers in the centuries following Ptolemy have all had to confront – changes in astronomical parameters as a consequence of elapsed time. A new model for the precession of the equinoxes is presented in order to account for such changes. Two time-related changes that this model addresses are the increase in the rate of precession and the decrease in the value of the obliquity of the equinox since the time of the *Almagest*. In addition, a theory of oscillation or periodicity of these motions ("trepidation") is proposed.

The other misattributed treatise deals with the solar year. The author of this work attempts to show why adopting a sidereal year is preferable to accepting Ptolemy's tropical year as the basic time-unit for solar motion.

In addition to his works in mathematical astronomy, Thābit also wrote on philosophical and cosmological topics, questioning some of the fundamentals of the Aristotelian cosmos. He rejected **Aristotle**'s concept of the essence as immobile, a position Rosenfeld and Grigorian suggest is in keeping with his anti-Aristotelian stance of allowing the use of motion in mathematics. Thābit also wrote important treatises related to Archimedean problems in statics and mechanics.

Thābit's efforts provided a foundation for continuing work in the investigation and reformation of Ptolemaic astronomy. His life is illustrative of the fact that individuals from a wide range of backgrounds and religions contributed to the flourishing of sciences like astronomy in Islamic culture.

JoAnn Palmeri

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Thackeray, Andrew David

Born **Chelsea, (London), England, 19 June 1910**
Died **Sutherland, (Western Cape), South Africa, 21 February 1978**

British-South African stellar astronomer Andrew Thackeray (always called David) was noted for his discovery with **Adriaan Wesselink** in 1952 of RR Lyrae stars in the Small Magellanic Cloud. This, in turn, demonstrated that the distance scale until then in use (which went back to **Harlow Shapley**) was too small by a factor of two, and the Universe therefore a factor of at least two older than had previously been supposed, removing most of the contradiction between the apparent age of the cosmos and the best estimates of solar and stellar ages.

Thackeray was the son of a classical scholar and a nephew of the solar physicist **John Evershed**. He was educated at Eton (1924–1929) and King's College Cambridge (1929–1933), where he studied mathematics. He started research work at the Solar Physics Laboratory, Cambridge during 1932–1934. From 1934 to 1936 Thackeray held a Commonwealth Fund Fellowship in Astrophysics and worked at the Mount Wilson Observatory in California, USA. There he studied the emission spectra of Mira variables and showed that fluorescence mechanisms similar to those then just discovered by **Ira Bowen** could explain some of the lines. This was the subject of his Cambridge Ph.D. dissertation in 1937. Thackeray served as chief assistant at the Solar Observatory in Cambridge from 1937 to 1948, except for a period of wartime service as an ambulance driver in Italy.

In 1948 Thackeray became chief assistant of the Radcliffe Observatory in Pretoria, then just completed. He became its director in 1950 and stayed in the post until the observatory was closed in 1974. His last years were spent as an honorary professor at the University of Cape Town. Thackeray was returning from an observing run with the Radcliffe 1.9-m reflector, which had in the meantime been moved to Sutherland, when he was killed in a freak accident.

On arrival in Pretoria in 1948, Thackeray found that he had almost unlimited observing time on the new telescope but rather minimal instrumentation to work with. He corresponded with **Walter Baade** about suitable programs to pursue and decided to investigate the globular-like clusters of the Magellanic Clouds as a priority. At the International Astronomical Union General Assembly in Rome in 1952 Baade announced that he had failed to detect RR Lyrae variables in M31 with the 200-in. telescope and that, therefore, it had to be further away than formerly believed. Immediately after he had finished speaking, Thackeray announced that he and Wesselink had actually detected RR Lyrae variables in NGC 121 in the Small Magellanic Cloud. Thus the absolute magnitudes of RR Lyraes and Cepheids could now be compared. The RR Lyraes were found to be 1.5 magnitudes fainter than predicted from the prevailing Cepheid distance scale, which therefore had to be wrong.

Another important campaign conducted by Thackeray with his collaborators Michael Feast and Wesselink was an investigation of the brightest stars in the Magellanic Clouds, which showed observationally the limits of stellar luminosity.

Thackeray's main area of expertise was stellar spectroscopy, and he took particular interest in the spectroscopy and long-term behavior of the eclipsing symbiotic variable AR Pav, the luminous galactic variable η Carinae, and the old nova RR Tel. He discovered the polarization of the halo of η Carinae, and his spectroscopic study of RR Tel is widely quoted.

As the director of the Radcliffe Observatory, Thackeray created an atmosphere where administrative matters were kept firmly at a minimal level and scientific discussion was very much encouraged. He never saw the necessity for seeking publicity, a fact that perhaps led to a lack of appreciation of his work in official circles. He had very wide interests in natural phenomena, and his publication list numbers about 300 items. He was an editor of *The Observatory* during 1938–1942. A fellow of the Royal Astronomical Society from 1933 onward, Thackeray was made an associate just days before his death. He was president of the Astronomical Society of Southern Africa in 1951–1952.

In 1944, Thackeray married Mary Rowlands, and they had four children.

Ian S. Glass

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Thaddaeus Hagecius

➔ **Hájek z Hájku, Tadeá**

Thales of Miletus

Born ***circa* 625 BCE**
Died ***circa* 547 BCE**

Thales was credited by **Aristotle** with founding Ionian natural philosophy. His fame as an astronomer is based more specifically on his purported prediction of a solar eclipse, an achievement that marks for some historians the beginning of western astronomical science.

One of the major intellectual traditions within pre-Socratic science between 600 and 400 BCE was that established and developed by the Milesians (after the city of Miletus; also Ionians, after the region, the present-day Turkish coast of Asia Minor). Of the new Greek communities that sprang up in Greece itself and across the Aegean Sea in Asia Minor, the most prosperous was Miletus. Now but lonely ruins inland from the coast because the river and harbor silted up long ago, Miletus was, in its time, the richest city in the Greek world.

One objective of Ionian science or philosophy – the two were not separate disciplines at this time – seems to have been to search for a basic substance or substances, which persist throughout all changes. The Ionians were more interested in cosmogony (the creation of the world) than in cosmology (the structure and evolution of the world).

According to Aristotle, writing more than two centuries after the fact, Ionian philosophers thought that matter or principles in the form of matter were the principle of all things:

> Most of the first philosophers thought that principles in the form of matter were the only principles of all things: For the original source of all existing things, that from which a thing first comes-into-being and into

> which it is finally destroyed, the substance persisting but changing in its qualities, this they declare is the element and first principle of existing things, and for this reason they consider that there is no absolute coming-to-be or passing away, on the ground that such a nature is always preserved for there must be some natural substance, either one or more than one, from which the other things come-into-being, while it is preserved. Over the number, however, and the form of this kind of principle they do not all agree; but Thales, the founder of this type of philosophy, says that it is water (and therefore declared that the earth is on water), perhaps taking this supposition from seeing the nurture of all things to be moist, and the warm itself coming-to-be from this.

Thales was reputed to be the wisest of the seven wise men or sages of Greece. Asked what was difficult, he answered "to know thyself." Asked what was easy, he answered "to give advice." Supposedly, Thales was the first mathematician to demonstrate that a circle is bisected by its diameter, that the angle of a semicircle is a right angle, and that angles at the base of an isosceles triangle are equal. An acerbic scholar has noted, however, that "inevitably there accumulated round the name of Thales, as that of Pythagoras (the two often being confused), a number of anecdotes of varying degrees of plausibility and of no historical worth whatsoever."

Thales is also credited with predicting a solar eclipse. According to the Greek historian Herodotus, writing in the 5th century BCE, more than a century after Thales:

> In the sixth year of the war, which they [the Medes and the Lydians] had carried on with equal fortunes, an engagement took place in which it turned out that when the battle was in progress the day suddenly became night. This alteration of the day Thales the Milesian foretold to the Ionians, setting as its limit this year in which the change actually occurred.

Either the warring parties took the eclipse of the Sun as a sign to cease fighting, or they were eager for any reason to cease and found the eclipse a convenient excuse.

Astronomical calculations indicate a total solar eclipse on 28 May 585 BCE at the place of the battle in northern Turkey, thus lending credence to Herodotus's history. Subsequent discussions have centered less on the credibility of the tradition itself and more on what methods Thales could have used to predict the solar eclipse. From a study of the periodic recurrence of solar eclipses, Thales might possibly have predicted a slightly later eclipse but taken credit for the 585 eclipse. It is not certain that the eclipse reported by Herodotus is the eclipse of 585; eclipses of 582 and 581 have been pointed to as other possibilities, though they were not total over Asia Minor. Also, some scholars dismiss the whole eclipse prediction legend as more myth than historic truth.

Another legend involving Thales has him providing a practical justification for the study of philosophy. This time Aristotle is the source, in his *Politics*:

> For when they reproached him [Thales] because of his poverty, as though philosophy were no use, it is said that, having observed through his study of the heavenly bodies that there would be a large olive-crop, he raised a little capital while it was still winter, and paid deposits on all the olive presses in Miletus and Chios, hiring them cheaply because no one bid against him. When the appropriate time came there was a sudden rush of requests for the presses; he then hired them out on his own terms and so made a large profit, thus demonstrating that it is easy for philosophers to be rich, if they wish, but that it is not in this that they are interested.

Thus did Thales demonstrate that philosophers could be rich in conventional monetary terms if they wished. The philosopher's true wealth, however, is not measured in money; it is found in the pleasure derived from intellectual endeavor. In eschewing a myopic pursuit of wealth, Thales demonstrated his wisdom again. Still, Thales was not always practical, as **Plato** noted in his *Thaetetus*: .

> Theodorus, a witty and attractive Thracian servant-girl, is said to have mocked Thales for falling into a well while he was observing the stars and gazing upward; declaring that he was eager to know the things in the sky, but that what was behind him and just by his feet escaped his notice.

Norriss S. Hetherington

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Theodosius of Bithynia

Born **Bithynia, (Anatolia, Turkey), *circa* 160 BCE**
Died ***circa* 90 BCE**

Theodosius compiled a three-volume text on spherical geometry, which was much used in the Middle Ages and Renaissance.

Euclid's *Elements of Geometry*, while no minor work, does not treat spherical geometry. Astronomers throughout the Hellenistic world thus hungered for a text on this important subject. This appetite was satisfied by Theodosius' three-volume *Spherics*. *Spherics* attracts little compliment from modern writers: The mathematician T. Heath, (1921) judged Theodosius "simply a laborious compiler," for "there was practically nothing original in his work." **Otto Neugebauer** observed that Theodosius failed to recognize the significance of the great-circle triangle, that his theorems seldom treat more than what is obvious, and that its Euclidean rigor is but cosmetic: his "proofs" do little more than reword the conjectures, and seldom does Theodosius admit his assumptions. Writers as early as **Pappus** commented that the *Spherics* had a very theoretical tone, that (in contrast to a competing text by **Apollonius**) it hardly ever indicated where in astronomy the mathematics might be applied. Yet the *Spherics* has proven useful enough to endure nearly as long as Euclid's *Elements:* The Greek manuscript was translated into Arabic in the 10th century, and thence into Latin by **Gerard of Cremona** (and perhaps **Campanus of Norara**) in the 12th century. A Latin edition was printed in 1518, soon followed by **Johannes Vögelin**'s much-improved translation of 1529. The *Spherics* inspired **Christoph Clavius** to produce a new Latin translation and commentary in 1586, of which an English translation appeared in 1721. Latin translations were published also by other influential thinkers such as Jean Pena (1558, including the first printing of the Greek text), **Francesco Maurolico** (1558), and Isaac Barrow (1675). Boring and unoriginal *Spherics* may have been, but useless and disregarded it was not.

Theodosius' other astronomical works include two books *On Days and Nights* and a 12-theorem book *On Habitations*. These works, which have survived, discuss how views of the stars and the lengths of night and day depend on the observer's location on the Earth, and which parts of the Earth have habitable climates. *On Days and Nights* treats the daily passage of the Sun, with a view to determining the conditions under which the solstice occurs on the meridian, and when equinoctial night and day are truly equal. One interesting conclusion is that, if the year is equal to an irrational number of days, then the stellar phases will show no annual periodicity.

Theodosius is credited also with a work on astrology (containing material important to astronomy), and a commentary on **Archimedes**' *Mechanics*, both of which are lost. Some fragments survive from his *Description of Houses*, which treats problems in architecture. On the practical front, **Vitruvius** credits Theodosius with inventing a universal sundial, but of this we know no details.

Alistair Kwan

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Theon of Alexandria

Born **Alexandria, (Egypt), *circa* 335**
Died **Alexandria, (Egypt), *circa* 400**

The details of the life of Theon, Greco–Egyptian mathematician, astronomer, and teacher of late antique Alexandria, are speculative and derive primarily from later accounts that are frequently confused or inaccurate. His predictions and observances of the solar and lunar eclipses of 364, however, establish that he was an active scholar at that time; similarly, he is said to have reached maturity during the latter two decades of the 4th century. A pagan, Theon served as the last member of the *Mouseion* at Alexandria and devoted himself especially to the study of older Greek religious practices and beliefs. Though he seems not to have actually taught philosophy, he was regarded as a philosopher in some later sources. He worked with associates such as his older contemporary **Pappus**, the mathematicians Orgines and Eulalius, and his student Epiphanius. Importantly, Theon was also the father of the Neoplatonist philosopher and mathematician **Hypatia** and was her closest associate and collaborator. His death is thought to have occurred before she was killed by a Christian mob in 415.

Theon's surviving works all ultimately derive from his activities as a professor, being chiefly commentaries on and explications of the works of earlier authors in the fields of mathematics and astronomy. In the case of the former, Theon produced reworked editions of several of Euclid's treatises: a highly influential edition of the *Elements*, along with an edition of the *Data* (on the basics of geometrical figures), and of the *Optics*, subsequently identified as student notes taken down during lectures. He also produced an edition of the Pseudo-Euclidean work on visual reflection, the *Catoptrics*. In general, Theon's mathematical contribution is slight, but he does offer insights into the Greek sexagesimal system as it was applied in calculation.

Theon's astronomical contributions are more significant, and his commentaries on the two major works of **Ptolemy** are partially extant. The more extensive of these is that on the *Almagest*, originally written in 13 books but now missing book 11 and most of book 5. The commentary itself is a reworking of Theon's own lectures and thus has been criticized as being merely a scholastic exercise. Its value, however, lies in its incorporation of information from lost works on which Theon relied, including that of Pappus. Theon also wrote two commentaries on Ptolemy's *Handy Tables*, claiming that he was the first to do so. The *Great Commentary* is fragmentary, with slightly more than three of its original five books now extant (books 1–3, the beginning of book 4). In describing how to use the Ptolemaic computations, it also explains the reasoning and calculations behind them, thus repeating some of the information in the commentary on the *Almagest.* There is some indication that Hypatia may have revised book 3. The *Little Commentary* on the *Handy Tables* survives complete in one book and is consciously directed at students limited in their geometrical and mathematical preparation. In it Theon discusses the theory later known as "trepidation," the variability of the rate of precession. It is thought that in the 7th century the Syrian **Severus Sebokht** used Theon's *Little Commentary* in conjunction with the *Handy Tables.*

Theon also wrote a now lost work on the astrolabe, called in the 10th century *Suda Lexicon* (Treatise on the small astrolabe); Arabic sources also attribute to him a work on the instrument. Significantly, while Theon clearly did not invent the astrolabe, his work served as the most important link transmitting its theoretical concepts from the Greek to the Islamic world and thence to Europe. Indeed, Sebokht's work on the astrolabe, which is still extant, was drawn from and preserves material from Theon's lost treatise.

Theon's name is also associated with a number of other lost works, including tracts on planetary movements, on the star Sirius, and on other natural occurrences. He seems also to have written commentaries on esoteric religious and magical texts as well as to have composed poetry, one extant example of which is in praise of Ptolemy.

John M. McMahon

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Theon of Smyrna

Born ***circa* 70**
Died ***circa* 135**

Known as "Theon the mathematician" by **Ptolemy**, "the old Theon" by **Theon of Alexandria**, and "Theon the Platonist" by **Proclus**, Theon is best remembered as the author of a handbook on Pythagorean harmony, and for several widely cited observations of Mercury and Venus. Recorded by Ptolemy, these observations (127, 129, 130, and 132) were later used to determine the maximum elongation of the inferior planets. They also confirm Theon's flourish dates; an extant stone bust fixes his death before 140. Nothing certain is known of his life, education, and related writings. Theon's most influential extant writing, *Theonis Smyrnaei Platonici Eorum, quae in Mathematicis ad Platonis lectionem utilia sunt, Expositio*, was first translated from Greek to Latin by **Ismaël Boulliau**, the noted French astronomer (Theon of Smyrna the Platonist, exposition of the works on mathematics useful for reading Plato, Paris 1644, Bks I and II).

Now consisting of three extant books (Arithmetic, Music, and Astronomy) Theon's *Exposition* was designed to introduce general readers to the Cosmic Harmony that binds the mathematical and natural worlds, thus opening a path (if not a royal road) to understanding **Plato**'s philosophy. It is not an original or technically demanding work. Instead, it moves simply but elegantly from number to arithmetic, geometry, music, and astronomy to the Harmony of the World. In practice, Theon begins by defining numbers, prime and geometrical, finally focusing on more sophisticated ratios, proportional ratios, and progressions. By tradition, the principal value of the *Exposition* is not its originality but its use as a historical source concerning ancient writers and lost texts.

Yet Theon's treatise can no longer be viewed simply as an ancient text. Seldom discussed, Boulliau's translation of the *Exposition* marked something of a modern revival in the wake of **Johannes Kepler**'s harmonic conjectures. Pythagorean speculations about the Harmonies of the World were of particular interest, especially the kinds of numbers: odd and even, prime and composite, square and oblong, circular and spherical, pyramidal and perfect. In Book II, Theon's treatment of music addressed not only the mathematical relations between intervals but the role of ratios in eccentric and epicyclic constructions. The resonance with Kepler is obvious. But if Theon's main interest was Cosmic Harmony, Part Three draws together his central themes. Echoing Adrastus, Theon begins with a systematic introduction to the elements of astronomy, the ordering of the planets, their retrograde motions (discussing epicyclic and homocentric models), and finally, the problem of planetary distances, which Theon plays skillfully against musical intervals of the octave. More generally, the "harmony of the world" is rooted in number and proportion, which govern all bodies and movements. Theon's concluding discussion of planetary motion on the surface of geometrical solids – on parallel circles and in spirals – suggests possibilities later explored and exploited by the New Science.

Theon's other works on astronomy and mathematics are lost, among them commentaries on Ptolemy and Plato's *Republic*, and reportedly, a history of Plato's ancestry. Principal manuscripts of Theon's *Exposition* (Greek) are found in Paris, Venice, Florence, Naples, and Rome; reports suggest an Arabic version has been recently discovered. Published editions of the *Exposition* have appeared piecemeal over the last three centuries. Following Boulliau's edition of Book I (Arithmetic) is J. J. de Gelder (Book I, Greek & Latin, Leiden 1827). Book II (Music) has not been retranslated into Latin; Book III (Astronomy) is in an edition by T. H. Martin (Greek & Latin, 1849; Gröningen 1971). The first complete Greek edition is Eduard Hiller (Books I–III, Greek, Leipzig 1878). The first complete translation was J. Dupuis (Books I–III, Greek and French, Paris 1892) and most recently, Joëlle Delattre (Greek–French). No complete English translation (from Greek or Latin) exists.

Robert Alan Hatch

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Theophrastus

Born **Eresos, Lesbos (Lésvos Greece), 372/371 BCE or 371/370 BCE**
Died **possibly Athens, (Greece), 288/287 BCE or 287/286 BCE**

Theophrastus wrote numerous works on topics ranging from formal logic to practical legislation and from ethics to meteorology.

Tyrtamus, son of Melantas, was his full name; "Theophrastus" was a nickname. The ancient tradition that he studied at **Plato**'s Academy (and there met **Aristotle)** may be unreliable. He certainly accompanied Aristotle in his travels and researches from 347 BCE onward, becoming a member of Aristotle's school in the Lyceum when it was founded in 335 BCE, and head of the school when Aristotle went into exile in 323 BCE.

The contribution to knowledge for which Theophrastus is best known, and the one in which his major works survive, is his establishing of botany as a formal science. Other areas of his activity are known through some shorter surviving treatises and through secondhand reports and quotations.

Theophrastus's contributions to astronomy can be considered under five heads:

(1) The explanation of the motion of each planet in the theory of **Eudoxus** and **Callippus** involved several spheres in addition to that actually carrying the planet. Aristotle's conversion of this mathematical theory into a physical one involved the addition of further counteracting spheres to cancel out the motion of each planet so that it would not affect those below it. We are informed that Theophrastus applied the terms "starless" to the former and "carrying round in the opposite direction" to the latter, and the implication is that he invented these terms. It is a reasonable though not certain supposition that he also accepted Aristotle's theory itself, but see (3) below.

(2) In the surviving short treatise now known as his *Metaphysics* (not its original title), Theophrastus raises serious objections to Aristotle's theory that the circular movement of the heavenly spheres is caused by their desire for God, the Unmoved Mover. It seems likely, though this is disputed, that Theophrastus rejected the theory of the Unmoved Mover altogether. It does however seem that he retained the view that the heavenly bodies themselves are living beings.

(3) In Aristotle's view the heavens are composed of an element, *aether*, unique to them and distinct from the four elements (earth, water, air, and fire) found in the terrestrial region. Whether Theophrastus retained this view is disputed. In sections 5–6 of his treatise *On Fire*, in the course of a complex and somewhat inconclusive discussion of the status of fire as an element and its relation to heat, he considers the possibility that the Sun itself is hot, which in Aristotle's theory it is not. (According to Aristotle, its heating effect is caused by friction between the *aether* and the air beneath it.) But ancient reports of Theophrastus's views suggest that he retained Aristotle's theory of *aether* as a distinct element, and it is not easy to see how he could have accepted Aristotle's theory of the heavenly spheres (earlier, (1)) if he did not do so. It is possible that his views changed during his career; but, as is often the case, the tentative and exploratory nature of his discussions (where they are preserved in their original form at all) means that we cannot be sure.

(4) Like Aristotle, Theophrastus regarded such phenomena as comets, because of their irregular nature, as occurring in the region near the Earth and as part of the study of meteorology rather than of astronomy. He followed Aristotle in linking comets with wind and drought; an alleged connection with earthquakes is less certain. The treatise *On Weather-Signs*, which includes reference to astronomical signs of the seasons and of the weather, is not a genuine work of Theophrastus in its present form, though the astronomical signs probably derive from him.

(5) The date at which the Greeks developed an interest in astrology (in the modern sense of the term, rather than in its earlier Greek usage for what we now call astronomy) is disputed. Theophrastus is recorded as having referred to the Chaldaeans foretelling the fortunes of individuals from the heavenly bodies;

this, if genuine, would be one of the earliest explicit references to astrology in Greek.

R. W. Sharples

Alternate name

Tyrtamus

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Thiele, Thorvald Nicolai

Born **Copenhagen, Denmark, 24 December 1838**
Died **Copenhagen, Denmark, 26 September 1910**

Thorvald Thiele was an observatory director and mathematician. He was the son of Just Thiele and Hanne Aagesen. In 1875, he was appointed professor of astronomy and director of the Copenhagen University Observatory, positions he held until 1907. Apart from his works in astronomy, Thiele contributed to statistics and the actuarial sciences. Thiele, who had bad eyesight, mostly worked in celestial mechanics. In his analyses of double star systems he developed what became known as the Thiele–Innes method. His most original work was in the mathematical theory of observations, published in 1903 as *Theory of Observations*.

Helge Kragh

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Third Earl of Rosse

➜ **Parsons, William**

Thollon, Louis

Born **Ambronay, Ain, France, 2 May 1829**
Died **Nice, France, 8 April 1887**

Louis Thollon was a specialist in high-dispersion spectroscopy who worked in Paris in the physical laboratories of the Sorbonne, the École Normale, and the Collège de France, and from 1879 at the observatories of San Remo, Italy and Nice. Thollon was awarded the Prix Lalande by the Académie des sciences in 1885 for his large map of the solar spectrum, published posthumously in 1890.

Inspired by the large-scale lithographic spectrum atlases of **Anders Ångström** and **Alfred Cornu**, Thollon set out to sketch, with the best possible likeness, the "physiognomy" of each group of lines in the Fraunhofer spectrum. For this program, a maximum increase in the resolving power of his spectroscope was crucial. In the late 1870s he worked on fine-tuning his direct-vision spectroscope by means of an intricate multi-prism arrangement to minimize the total angle of deviation while maximizing the dispersion. Thollon's first arrangement from 1878, which employed eight glass prisms, attained an angle of 30° between the Fraunhofer lines B and H. Sixfold enlargement of this spectrum produced a total length of over 1 m.

In that same year, Thollon changed the prism combination to two of crown-glass and one fluid-filled, containing a mixture of ether and carbon bisulphide, carefully prepared to have the same index of refraction as the glass prisms. The prisms were positioned face to face without any air gap and were of the same index of refraction, so there was considerably less loss of light due to reflection. When his Parisian optician and precision instrument maker Léon Louis Laurent assembled two such block prisms into a prototype direct-vision spectroscope, Thollon realized what enormous dispersions were now within grasp: 12 ft. between the two D lines, equivalent to a prism chain of 16 carbon-bisulphide prisms or 30 glass prisms with a refractive index of 1.63. This instrument enabled him to verify by experiment the Doppler shift caused by the solar rotation in spectra from the solar limb. He also developed a device that allowed him to record the details of the thus generated spectra far more efficiently.

This work had been conducted at the Sorbonne, the École Normale, and the Collège de France. The next stage, mapping the full visible portion of the solar spectrum at this unprecedented dispersion, could not be carried out in Paris due to weather conditions.

For the greater part of 1879 Thollon worked in the private observatory of Prince Nicolas d'Oldenbourg in San Remo. Given clear skies and his ingeniously contrived apparatus, Thollon finished in under 3 months a 10–15 m-long drawing of the solar spectrum displaying approximately 4,000 spectrum lines between A and H. This map was presented to the Académie des sciences in late 1879 but was never published because, meanwhile, Thollon had embarked on an even more ambitious mapping project at the newly founded Observatoire de Nice. He had already had some dealings with that observatory (still under construction at the time) as scientific consultant for its spectroscopic equipment. This prestigious site, with which France hoped to compete against the new observatories in Potsdam and Strasbourg, was where Thollon set his four prisms, two of them of a high-dispersion carbon-bisulphide type, in a special mounting that guided the incident light twice through each prism.

This arrangement yielded a dispersion of 70° (or 30 mm on the map) between the two yellow sodium D lines, the optimum attainable with prism chains because of the significant loss in light intensity to each prism along the optical path. Only the big Rowland concave gratings (and later interferometric measurements) could achieve even higher dispersions. Thollon secured a constant ambient temperature for his strongly temperature-dependent bisulphide-of-carbon fluid prisms, by having water circulate within the table on which the spectroscope was mounted, and additionally by enclosing the whole instrumental setup within a double-walled metal box suspended from the ceiling. In a half-decade of assiduous labor, Thollon mapped 3,448 lines in roughly one half of the optical part of the spectrum from the visible red to the middle green (from 7600 Å to 5100 Å). Unfortunately, he died before his *magnum opus* was finished, which was eventually published in 1890 at the expense of Raphaël Bischoffsheim, the financier of the Nice Observatory.

Increased resolution of his map was not the only feature with which Thollon tried to improve upon his forerunners. He gave a fourfold representation of the solar spectrum: With the Sun near the horizon; at 30°; in a normal and dry atmosphere; and finally, omitting the atmospheric lines altogether. Of the 3,202 dark spectrum lines listed in Thollon's accompanying table, 2,090 were of purely solar origin, 866 of atmospheric absorption lines, and 246 were labeled "mixtes." It was this feature that resulted in the continued use of his map, well after **Henry Rowland**'s photographic maps of the normal spectrum of 1886 and 1888 became available. The latter had dispersions of between 4.8 and 2.4 Å per centimeter, depicted nearly 20,000 Fraunhofer lines, and were generally considered to be far superior to all foregoing lithographs.

It is significant that both Cornu and Thollon were appreciated by their colleagues for their unique combination of scientific and artistic talents. Thollon's beautiful drawings of the spectrum, which cost him 6 years of labor, plus another 3 for his engraver to transfer onto steel plates, marks the climax of the tradition of spectrum portraiture, which sought not only to plot the precise location of each spectral line, but also to portray its character.

Klaus Hentschel

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Thom, Alexander

Born **Mains Farm near Carradale, (Strathcyle), Scotland, 26 March 1894**

Died **Fort William, (Highland), Scotland, 7 November 1985**

Alexander Thom was pivotal in the development of the discipline of archaeoastronomy.

Alexander Thom's father was a dairy farmer and his mother, the daughter of a Glasgow muslin manufacturer. After school in Ayrshire, Alexander studied civil engineering at the Royal Technical College, Glasgow and was awarded its associateship in 1914. He then studied engineering at the University of Glasgow, gaining a B.Sc. in 1915. Thom married Jeanie Boyd Kirkwood in 1917, and they had three children: Archibald, Alan, and Beryl.

For a few years Thom worked for various engineering and aeronautical firms in Glasgow. In 1921 he returned to the University of Glasgow as a lecturer, where he remained until 1939, gaining a Ph.D. in 1926 and a D.Sc. in 1929. During World War II Thom worked at the Royal Aircraft Establishment, Farnborough. In 1945 he was appointed professor of engineering science at the University of Oxford and fellow of Brasenose College, and held those positions until his retirement in 1961. Thom received several honorary degrees: an MA from the University of Oxford in 1945, an LLD from the University of Glasgow in 1960, and an LLD from the University of Strathclyde in 1976. He was a fellow of the Royal Astronomical Society, elected in 1957, and a member of the British Astronomical Association.

Thom's professional career was in engineering. Most of his professional work in this field was concerned with developing techniques for the numerical solution of the partial differential equations that arise in fluid mechanics. These techniques were applied to various types of fluid flow and are summarized in a book written late in his career. Though they predate the introduction of electronic computers, they proved readily adaptable for use with these new devices.

However, Thom was interested in astronomy from an early age. (Indeed, his first scientific paper, published while he was still an undergraduate, was on an astronomical topic.) Another long-standing passion was sailing, and it was a visit to the stone circle at Callanish on the Isle of Lewis, during a sailing trip in 1933, that prompted the investigations into ancient astronomy for which Thom is best known.

Starting in 1933 and continuing for the next 40-odd years, Thom made the first extensive and accurate surveys of the standing stones and stone circles found in Britain and Brittany. Such "megaliths" are common in Britain, Ireland, and Brittany, and are usually considered to have been erected between 4000 and 1500 BCE, during the Neolithic (New Stone Age) and early to middle Bronze Age. Thom surveyed several hundred megaliths, a task of considerable difficulty as many of the sites are in remote and inhospitable locations. This achievement is all the more remarkable in that it was pursued independently of his career in engineering and was initially carried out during vacations. However, following his retirement in 1961, Thom was able to work full-time on his astronomical studies. He published his first paper on this work in 1954 and his first book in 1967. Several members of Thom's family contributed to the work, and in particular his later books were written with his eldest son Archibald (who also followed a career in engineering fluid mechanics).

Thom drew three broad conclusions from the analysis of his surveys. These conclusions are separate and stand independently of each other. First, many of the rings were constructed in shapes other than simple circles. Second, they were constructed using a standard unit of measurement, which he called the "megalithic yard." Finally, many of the sites had significant astronomical alignments (hence the term "megalithic astronomy" often applied to this field), perhaps pointing to the rising and setting positions of the Sun on the summer or winter solstice. Many of the alignments proposed by Thom were remarkably precise and would imply considerable sophistication on the part of the builders of the monuments.

The reaction to Thom's ideas was mixed. Among astronomers it was broadly favorable, though there was debate about individual alignments and concern about the statistical significance of the results. The ideas were less well received by archaeologists, perhaps because Thom made no attempt to reconcile his proposals with the generally accepted understanding of the period; indeed he disclaimed any expertise in archaeology. Many archaeologists caviled at the idea that the preliterate societies thought to have erected the megaliths could have mastered the relatively advanced mathematics and astronomy implied by Thom's results. Similarly, the suggested use of a standard megalithic yard over an extended geographic area and for a protracted period of time seemed ill-matched to the conventional view of a shifting patchwork of local tribal cultures.

Before Thom it was known that some stone circles were not accurately circular. However, he was the first to show that the rings were deliberately constructed with a noncircular shape, rather than being a poor attempt at a circle, though the precise geometrical constructions that he proposed are not now widely accepted. Similarly, the idea of the megaliths having astronomical alignments predates Thom's work; it goes back to at least Sir **Norman Lockyer**, if not to the antiquarian **William Stukeley**'s writing in 1740. However, Thom recognized that astronomical alignments are common in these monuments. Precise alignments of the sort that he proposed are no longer widely accepted, but it is believed that many megalithic sites incorporate astronomical symbolism and some approximate alignments, mostly lunar, but also some solar.

In addition to attracting the attention of astronomers and archaeologists, Thom's work aroused considerable public interest. Popular accounts appeared in numerous magazine articles and were featured in several balanced and well-produced programs broadcast on British television.

The real significance of Thom's work is that he recognized the importance of extensive, accurate, and systematic surveys of megalithic monuments, and amassed a large body of accurate data on several hundred such sites. Modern studies of the astronomy of megalithic monuments date from his work.

A. Clive Davenhall

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Thome, John [Juan] Macon

Born **Palmyra, Pennsylvania, USA, 22 August 1843**
Died **Córdoba, Argentina, 27 September 1908**

Córdoba Observatory director John Thome played a dominant role in compiling the most extensive and widely used visual catalogs of Southern Hemispheric stars. Thome was admitted to Lehigh University in 1866, and was awarded the degree of C.E. (civil engineer) in 1870. Thome was one of several assistants recruited by **Benjamin Gould** to accompany him to Argentina and establish that country's first national observatory at Córdoba. Having gained the support of Argentina's newly elected president, Domingo F. Sarmiento, Gould wished to extend the precise mapping of Southern Hemisphere stars to the same level of accuracy accomplished by the northern *Bonner Durchmusterung* star catalog of **Friedrich Argelander**.

Thome and Gould arrived at Córdoba at the end of September 1870, before construction of the Observatory had begun. (Dedication took place 24 October 1871.) The team's first project was to prepare an atlas of all stars visible to the unaided eye, of which Thome obtained the bulk of the observations. This work appeared as *Uranometria Argentina* (1879), and would earn a Gold Medal from the Royal Astronomical Society, in 1883. Despite Thome's lack of formalized training or experience in astronomy, "his subsequent career and the excellent work … accomplished at Córdoba Observatory show[ed] the wisdom of Dr. Gould's selection."

The remainder of Gould's plan called for precise measurements of fainter stars in successive zones and publication of the corresponding catalogs. As Gould's senior assistant, Thome increasingly assumed a greater part of this task. During Gould's absences in 1874, 1880, and 1883, Thome served as acting director. Following Gould's permanent return to the United States in 1885, Thome became the Observatory's second director and held this post until his death.

Thome's career of service to Argentina, to the Observatory, and the world's astronomical community, was manifested in his realization of Gould's vision. Thome supervised publication of the *Córdoba Zone Catalogues* (starting 1884) and the *Argentine General Catalogue* (starting 1886), which culminated in the *Córdoba Durchmusterung* (starting 1890). Those four volumes produced under Thome's guidance contain the positions and brightnesses of 630,000 stars, compiled from some 1.8 million observations.

During the severe economic depression of the 1890's, Thome faced extremely difficult circumstances. Collapse of the Argentinian economy and bankruptcy of the government made it nearly impossible to retain sufficiently skilled workers. Anti-American sentiments arose during the Spanish–American War, further hindering his institution's tasks. To an extent now impossible to measure, Thome received valuable assistance from his wife during this critical period.

Thome's enormous labors did not go unnoticed. In 1888, he was awarded an honorary doctorate by Lehigh University. The *Córdoba Durchmusterung*, however, was only completed by Thome's successor, **Charles Perrine**. Both this catalog and its counterpart, the *Bonner Durchmusterung*, form the basis of star catalogs used by astronomers to the present day. Thome was elected a foreign associate of the Royal Astronomical Society on 10 November 1899. In 1901, he was awarded the Lalande Prize of the French Academy of Sciences in recognition of his achievements.

With the return of improved economic and political conditions in 1900, Thome attended the International Astronomical Congress held in Paris, as the delegate from Argentina. There, he offered the services of Córdoba Observatory toward completion of the *Carte du Ciel* Astrographic Chart and Catalogue, a planned photographic atlas of the heavens. Córdoba adopted that portion of the sky that was originally assigned to the La Plata Observatory at Buenos Aires, Argentina. New equipment was ordered, and the work was begun under Thome's tenure, although the massive *Carte du Ciel* itself was never completed.

Apart from his preparation of the star catalogs, Thome conducted observations of minor planets, comets, variable stars, and the 1874 transit of Venus. Between 1877 and 1906, he served as the United States vice consul at Córdoba, although this title carried little responsibility. While Thome spent the majority of his adult life in South America, he never became a naturalized citizen, but instead retained allegiance to the United States.

Durruty Jesús de Alba Martínez

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Thomson, George Paget

Born **Cambridge, England, 3 May 1892**
Died **Cambridge, England, 10 September 1975**

British experimental physicist Sir George Paget Thomson shared the 1937 Nobel Prize in Physics with Clinton J. Davisson for the discovery of electron diffraction, which demonstrated that subatomic particles also have wave properties, as part of the wave–particle dualism of quantum mechanics. He also chaired the committee that persuaded the British government, early in World War II, to become involved in the development of nuclear weapons.

George Thomson was the only son of the famous Joseph John Thomson (1856–1940; Nobel Prize in Physics 1906) and his wife Rose Paget, and he grew up in the privileged environment of the Cambridge elite. Thomson received his early education at the Perse School in Cambridge. He entered Trinity College in Cambridge in 1910, and in 1914 he earned first-class honors in mathematics and physics. Thomson took up postgraduate work under his father at the Cavendish Laboratory and became a mathematical lecturer at Corpus Christi College, Cambridge (until 1922).

When Britain entered World War I, Thomson immediately enlisted and was on the frontlines in France as a second lieutenant in the Royal West Surrey Regiment by November 1914. He was returned to England in 1915 as part of a group at the Royal Aircraft Factory working on the stability and performance of aircraft at Farnborough. **Francis Aston** was also part of this group. Thomson's first textbook, *Applied Aerodynamics* (1919), was the outgrowth of this experience. He also served as an advisor to the Air Ministry during the latter part of World War II.

After returning to Cambridge, Thomson resumed research on the behavior of electrical discharges in gases. In 1922 he became professor of natural philosophy (physics) at the University of Aberdeen, and (after a stay in 1929/1930 at Cornell University) in 1930 he was appointed professor at Imperial College, London. In 1952, Thomson became master of Corpus Christi College, Cambridge; from this position he retired in 1962.

Thomson was married and had four children. He was elected a fellow of the Royal Society in 1930, and, among other honors, he received the Hughes Medal (1939) and the Royal Medal (1949) of that society.

At the Oxford meeting of the British Association for the Advancement of Science in 1926 one main point of discussion was Louis de Broglie's (1892–1987) wave theory of matter. This stimulated Thomson to adapt certain experiments, which he had undertaken on scattering of (positive) anode rays, for testing this theory. He (together with Alexander Reid) passed electrons through a thin celluloid foil onto a photographic plate behind the foil, and the plate revealed a diffraction pattern, thus indicating the wavelike behavior of electrons. Experiments with thin metallic foils validated this result.

At the same time Clinton J. Davisson (1881–1958) – who had taken part in the 1926 conference, too – together with Lester H. Germer (1896–1971) at Bell Telephone Laboratories independently came to the same result from a similar experiment. In 1937 Thomson and Davisson shared the Nobel Prize for Physics for the experimental discovery of the diffraction of electrons by crystals. While Thomson in 1926/1927 had shown the wavelike character of electrons, his father, about 30 years previously, had demonstrated their particle character.

During the 1930s, Thomson moved his interest more and more to nuclear physics. With J. A. Saxton he looked for artificial radioactivity from positron bombardment, and together with another group of coworkers he studied the velocity distribution of slow neutrons. Thomson's last original work was on special cosmic-ray effects.

As World War II approached, Thomson was among the first to appreciate the significance of multiple slow neutrons coming out of natural uranium samples, and he urged the British government to buy up the Belgian stock of uranium residue. (They did not.) In April 1940, after the memorandum from Rudolf Peierls and Otto Frisch made clear to all knowledgeable readers that chain reactions in uranium would be possible, Thomson was appointed chair of the Maud Committee to investigate the implications. They reported in July 1941 that a superbomb could be made of istopically separated uranium-235. At this point, James Chadwick (discoverer of the neutron) was put in charge of the project and Thomson was sent to head the British Scientific Office in Canada. He returned to the Air Ministry in 1943.

After the war, Thomson became interested in the peaceful application of thermonuclear fusion. During his last years he was an engaged and passionate organizer and popularizer of science.

Horst Kant

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Thomson, G. P. and A. Reid (1927). "Diffraction of Cathode Rays by a Thin Film." *Nature* 119: 890.

Thomson, William

Born **Belfast, (Northern Ireland), 26 June 1824**

Died **Netherhall near Largs, (Strathclyde), Scotland, 17 December 1907**

William Thomson calculated the age of the Earth from its cooling rate, and concluded that it was too short to fit with Charles Darwin's theories of evolution. As Lord Kelvin, he is commemorated in the Kelvin temperature scale and the Kelvin–Helmholtz time scale.

Thomson's father, James Thomson, held the chair of Mathematics at Glasgow University. His mother died when William was 6 years old. William learned mathematics from his father, and became adept in that field at a very young age. He was admitted to Glasgow University at age 10, and began what we would now consider university-level work at 14.

Thomson won a medal from the University of Glasgow when he was 15, for an essay entitled "Essay on the Figure of the Earth." This essay contained many important ideas that he returned to repeatedly in his later career. Thomson was strongly influenced by the French mathematical approach to physical science, including the works by Joseph Fourier, Augustin Fresnel, **Adrien Legendre**, **Pierre de Laplace**, and **Joseph Lagrange**.

At the age of 17, in 1841, Thomson entered Cambridge University and published his first paper, on Fourier series. Papers on heat and electricity followed later in his undergraduate career. He graduated in 1845, becoming second wrangler in the mathematical *tripos* of 1845. Thomson was elected a fellow of Peterhouse College, Cambridge.

Thomson studied in Paris in the physical laboratory of Victor Regnault and had deep discussions with **Jean Biot**, Augustin Cauchy, Joseph Liouville, François Sturm, and J. B. Dumas. In 1846 he was elected to the chair of natural philosophy at Glasgow, with the help of his father.

Thomson collaborated closely with **George Stokes** on the theory of heat and its relation to the theory of fluids. In 1848, he proposed the absolute scale of temperature. The Kelvin scale of temperature derives its name from the title that Thomson was given by the British government in 1892: Baron Kelvin of Largs.

In 1852 Thomson observed the Joule–Thomson effect, namely the decrease in the temperature of gas when it expands in a vacuum. James Joule influenced Thomson's ideas, which were developed into a dynamical theory of heat that became the foundation for what we now know as statistical mechanics.

He was then led into the study of electricity and magnetism, and his ideas became the foundation on which **James Maxwell** built his remarkable new theory of electromagnetism. However, Thomson developed his own ideas differently, and diverged from Maxwell's viewpoint, is not accepting the existence of the displacement current.

Thomson was knighted in 1866 for work on the transatlantic cable connection; he had invented a very sensitive mirror galvanometer. He published more than 600 papers. Thomson was elected to the Royal Society in 1851 and was its president from 1890 to 1895.

In applying thermodynamics to cosmogony, Thomson foresaw the heat death of the Universe. He had an interest in the age of the Sun, and assumed its radiant energy came from the gravitational potential of matter that had fallen into it. Thomson estimated the Sun's age at 50 million years. The ideas he put forward were closely related to those earlier expressed by **Julius Meyer** and **John Waterston**, some of whose work he had seen.

David Jefferies

Alternate names

Baron Kelvin of Largs
Lord Kelvin

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Tikhov, Gavril Adrianovich

Born **Smolevichi near Minsk, (Belarus), 1 May 1875**
Died **25 January 1960**

Pulkovo Observatory's Gavril Tikhov (and Meudon's **Charles Nordmann**) "demonstrated" that light of different wavelengths, propagating from the same astronomical source, arrives at different times. The demise of this theory, the Nordmann–Tikhov effect, is explicated by Hendrik van de Hulst in "Nanohertz Astronomy" (Sullivan, 1984).

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Timocharis

Flourished **first half of third century BCE**

Timocharis was one of the first astronomers in the school of Alexandria, and was a near-contemporary of **Aristarchus** of Samos. Little is known of him, except that he made astronomical observations during the approximate period 295 to 270 BCE. He may have founded a school, but if so then **Aristyllus** is the only member whose name is known.

Timocharis and Aristyllus are usually considered to have compiled the first true catalog of the fixed stars, in which stars are identified by numerical measurements of their positions. (In earlier lists, stars had been identified by descriptions of their locations, typically with respect to other stars and constellations.) The catalog is not extant. Indeed, while Aristyllus and Timocharis certainly amassed a set of numerical observations of star positions, it is not, strictly speaking, known whether these observations were assembled into a catalog or table. Probably fewer than a hundred stars were observed, and the positions were reputedly of low accuracy. Observations by Timocharis or Aristyllus survive in **Ptolemy**'s *Almagest* for some 18 stars.

The observations of Timocharis and Aristyllus were practically the only historical measurements of the positions of the fixed stars available to **Hipparchus**, who used them in combination with his own observations to discover the precession of the equinoxes. This discovery is probably the most important use to which they were put. However, much later **Edmond Halley** also used the observations of Timocharis, among others, to demonstrate the existence of proper motion.

Timocharis observed the planets as well as the fixed stars, and two observations that he made of Venus are preserved in the *Almagest*.

In *De Pythiae oraculis* (402 F) Plutarch includes Timocharis in a list of astronomers who wrote in prose. However, most of the information about him comes from Ptolemy's *Almagest*, particularly the discussion of precession and its discovery by Hipparchus.

A. Clive Davenhall

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Tisserand, François-Félix

Born **Nuits-Saint-Georges, Côte d'Or, France, 13 January 1845**
Died **Paris, France, 20 October 1896**

François-Félix Tisserand, known by the first name Félix, was born in the Burgundy region known for growing good wine. Together with a brother, he was the son of a cooper who died when Félix was still young. Tisserand entered the École Normale Supérieure when he was 18, graduating first in his class. At that time **Urbain Le Verrier** was the director of the Observatoire de Paris. Le Verrier recruited the bright Tisserand to find mistakes in **Charles Delaunay**'s lunar theory.

After passing his *Doctorat d'Etat* in 1868, Tisserand showed particular interest and value in the field of celestial mechanics. On the other hand, he was participating in astronomical expeditions such as the solar eclipse of 1868 and the transits of Venus in 1874 and 1882.

In 1873, Tisserand was appointed director of the Observatoire de Toulouse, reorganizing and reequipping it in such a way that it became a valuable astronomical center. In 1878 he was asked to teach at the Sorbonne, Paris, in celestial mechanics. Tisserand soon became a specialist in the last subject, establishing what is called the "critère de Tisserand," employed to know if a comet is new or if it is a returning object. He became director of the Observatoire de Paris in 1892, following his predecessor, admiral **Ernest Mouchez**, in particular with regard to the international enterprise, the *Carte du Ciel*.

Since the celebrated *Principia* by **Isaac Newton** and the *Mécanique céleste* by **Pierre de Laplace** one century earlier, nothing of great value had been published in the general field of celestial mechanics during the 19th century. The *Traité de mécanique céleste*, rigorous and clearly written by Tisserand, was published in four volumes, the last one appearing the year he died. Volumes I and II of his *Traité* were reedited in 1960 as was the complete set in 1990. After reading Newton and Laplace, specialists must read Tisserand to best understand **Jules Henri Poincaré** and **Albert Einstein**.

Tisserand was married twice. His first spouse died soon after their daughter was born. He had two more daughters from his second marriage.

In 1878, Tisserand succeeded Le Verrier as a member of the Académie des sciences. He was appointed as a member of the Bureau des longitudes in 1878.

Suzanne Débarbat

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Titius [Tietz], Johann Daniel

Born **Konitz, (Chojnice, Poland), 2 January 1729**
Died **Wittenberg, (Germany), 11 December 1796**

Johann Titius was a German physicist, astronomer, and biologist, known for the discovery of the so called Titius–Bode law. He studied at the University of Leipzig and became professor of physics at Wittemberg in 1756.

His work in physics (especially thermometry), biology, and mineralogy being totally forgotten, Titius is remembered for his law on planetary distances, also known as Bode's law or the Titius–Bode law. This law, which is in fact more an empirical rule, was formulated by Titius as follows: If the distance Sun–Saturn is taken as 100, then Mercury is found at a distance of 4 from the Sun, Venus at 4 + 3 = 7, the Earth at 4 + 6 = 10, Mars at 4 + 12 = 16 (no planet being found at the distance 4 + 24 = 28), Jupiter at 4 + 48 = 52, and Saturn 4 + 96 = 100.

Titius formulated his discovery as a brief remark in his own 1766 adaptation in German of the then well-known book *Contemplations de la nature* by the Swiss philosopher Charles Bonnet. It remained unnoticed until **Johann Bode**, a much better-known astronomer, formulated the same scheme in 1772. Although Bode's note was nearly identical to Titius's, he did not refer to the older source, and it was not before 1823 – Titius being long since dead and forgotten – that Bode admitted to have read it. Both Titius and Bode were convinced that the Creator could not have left the space between Mars and Jupiter empty, but – and this is the only difference between the two theories – Bode clearly presumed the existence of an unknown planet in that sector, while Titius only speculated that this space was filled by yet undiscovered satellites of Mars and Jupiter.

Titius acknowledged to having been inspired by the German rationalist philosopher Christian Wolff, who had tried before to formulate some numerical regularity in the distance between the planets, and by the German mathematician and astronomer **Johann Lambert**, who, in his *Cosmologische Briefe* (1761), had asked if perhaps some planets were missing in the vast space between Mars and Jupiter.

Tim Trachet

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Todd, Charles

Born **Islington, (London), England, 7 July 1826**
Died **Adelaide, South Australia, Australia, 29 January 1910**

Sir Charles Todd established the Adelaide Observatory and directed its astronomical work for over 51 years. He is probably best remembered for overseeing the construction of the Australian transcontinental telegraph line from Adelaide to Darwin, completed in 1872. In addition, Todd established a network of weather stations and laid the foundations of the Australian Bureau of Meteorology.

The elder son of George Todd, a grocer and tea merchant who lived at Greenwich in London, Charles, at the age of 15, found employment at the Royal Observatory in Greenwich as a computer under **George Airy**, the Astronomer Royal. He held this post until the end of 1847, being engaged on lunar reductions. In 1848, Todd was appointed assistant astronomer at the Cambridge University Observatory and was put in charge of the Northumberland Equatorial. He made observations of the newly discovered planet Neptune and took a daguerreotype of the Moon, one of the earliest attempts at astronomical photography. In addition, Todd helped to determine the difference in longitude between Cambridge and Greenwich by means of the electric telegraph.

In 1854, Todd was recalled to Greenwich to take charge of the new time signal apparatus. In this position he was responsible for the transmission of time signals throughout England and for the dropping of time balls. In early 1855, Airy recommended Todd for the new posts of superintendent of telegraphs in the South Australia colony and director of Adelaide Observatory. Todd was appointed to those positions on 10 February, and married Alice Gillam (*née* Bell) in April; they arrived in Australia in November 1855. Todd immediately started taking meteorological observations, made plans for a telegraph network, and supervised construction of an observatory.

Despite all his other duties, Todd maintained a keen interest in astronomy and fully executed his duties as government astronomer. Completed in 1860, the Adelaide Observatory was equipped at first with only a 42-in. focal length transit instrument on loan from the government of Victoria. Todd observed the transits of Mercury in November 1861 and November 1868 with a Dollond refractor of 2¼-in. aperture. In 1868 he cooperated with the government astronomers in Victoria and New South Wales in the determination of a more accurate 141st meridian, later adopted as the common boundary between South Australia and New South Wales.

Todd observed the 1874 transit of Venus with a new 8-in. aperture Cooke equatorial equipped with a spectroscope and micrometer. The Cooke telescope was subsequently used for extensive observations of the motions of Jupiter's satellites, for the positions of comets, and for studying features of the planets. A 6-in. transit circle by Troughton and Simms was installed later, and a program of regular observations was begun in 1891. A founding member of the Astronomical Society of South Australia in 1892, Todd served as its first president until his death. When consulted by the government of Western Australia in 1895 about establishing a new observatory, Todd chose a site on Mount Eliza on the outskirts of Perth. He observed the annular eclipse of the Sun in March 1905 and the partial solar eclipse in February 1906.

Under Todd's supervision, eventually as postmaster general of Australia managing both the postal and telegraphic services, a telegraphic network extending over 5,000 miles of mostly unmapped territory was completed between 1856 and 1872. The network linked major cities in Australia to England *via* a transoceanic cable from Darwin through Java to Singapore; communication with England opened in October 1872. Todd achieved similar progress in weather observation and forecasting by equipping and training postal supervisors at 357 meteorological stations and 2,575 rainfall stations in Australia and New Zealand. Todd provided weather forecasts and pioneered in the production of weather maps.

Todd was made a companion of the Order of Saint Michael and Saint George in 1872 for his work on the continental telegraph system. He was elected a fellow of the Royal Society in 1889 and received a knighthood in 1893 for his public services. Todd held an honorary MA from the University of Cambridge and was a fellow of the Royal Meteorological Society and the Society of Electrical Engineers in addition to being a fellow of the Royal Astronomical Society.

In his later years Todd ruled his departments as a "benevolent autocrat," respected both by his employers and by his employees. He was so highly regarded that the South Australian parliament deliberately delayed compulsory retirement laws until the esteemed octogenarian retired of his own volition. Todd retired as postmaster general in 1905 and as government astronomer at the end of 1906, having served for over 51 years in the latter office.

Todd died of gangrene and was buried in Adelaide. He was survived by one son, Dr. C. E. Todd and four daughters, Lady Todd and his eldest son having predeceased him. In 1898, his daughter Gwendoline married (Sir) William Bragg, professor of mathematics and physics at the University of Adelaide.

David W. Dewhirst

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Todd, David Peck

Born **Lake Ridge, New York, USA, 19 March 1855**
Died **Lynchburg, Virginia, USA, 1 June 1939**

David P. Todd was a versatile astronomer with a career that covered over 50 years. His base of operation was Amherst College, but he is probably best known for his many expeditions to observe astronomical phenomena all over the world.

After growing up on a New York farm, Todd received bachelor's (1875) and master's (1878) degrees from Amherst College. (His honorary doctorate was from Washington and Jefferson College.) Todd became professor of astronomy and director of the observatory at Amherst in 1881 after a brief stay at the United States Naval Observatory (USNO), working under **Simon Newcomb**.

Todd married Mable Loomis in 1879. (She is better known as the editor of Emily Dickinson's poetry.) The couple had one daughter, Millicent.

Todd participated in the 1978 Naval Observatory eclipse expedition to Texas, and led many other eclipse expeditions. He reduced the USNO's 1874 transit of Venus plates and was in charge of the Lick Observatory heliometric observations of the transit in 1882. (Neither data set resulted in a satisfactory solar parallax.)

Todd became a close friend and associate of **Percival Lowell,** who financed and accompanied him on a 1900 eclipse expedition to

Tripoli. Lowell also sponsored his trip to observe Mars from Chili, and sent **Earl Slipher** along as his assistant. Todd became a proponent of attempts to contact Mars *via* radio. He was institutionalized in 1922.

Todd was an active member of national and international astronomical societies, and the author of several books on astronomy. He contributed many articles to leading astronomical journals and magazines.

Henry L. Giclas

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Tolman, Richard Chace

Born **West Newton, Massachusetts, USA, 4 March 1881**
Died **Pasadena, California, USA, 5 September 1948**

American chemist and mathematical physicist Richard Tolman was a pioneer in applying the ideas of general relativity and of thermodynamics to the large-scale structure of the Universe. He received a BS from the Massachusetts Institute of Technology [MIT] in 1903, and, after a year of study and work in an industrial chemistry laboratory in Germany, entered the MIT graduate program in the chemistry laboratory of Arthur Amos Noyes, receiving a Ph.D. in 1910 with a thesis on measurement of the electromotive force in rotating, conducting solutions. In 1909, Tolman and Gilbert N. Lewis (a fellow chemist, and also a native of West Newton, working in Noyes's lab) wrote the first American exposition on special relativity.

Tolman held academic positions at the universities of Michigan (1910/1911), Cincinnati (1911/1912), California (1912–1916), and Illinois (a full professorship of physical chemistry, 1916–1918). He worked largely in laboratory chemistry and chemical kinetics, coming to the conclusion that thermodynamic equilibrium was not usually a good description of the results of chemical reactions.

After the United States entered World War I, Tolman took a position with the Chemical Warfare Service. Noyes felt strongly that scientific involvement with government operations should continue after the war and arranged a position for Tolman as associate director and then director (1919–1922) of a laboratory working on fixation of nitrogen for explosives and fertilizers. Noyes moved on to the California Institute of Technology (Caltech) and brought Tolman there in 1922 as professor of physical chemistry and mathematical physics, where most of the work we remember him for was done. Tolman remained associated with Caltech the rest of his life, though from 1940 onward he held a variety of advisory wartime positions as vice chairman of the National Defense Research Council, scientific advisor to General Leslie Groves on the atomic bomb project, and United States advisor to the United Nations Atomic Energy Commission (1946 until his death).

In 1924 Tolman married psychologist Ruth Sherman whom he had met through his brother, Edward Chace Tolman (a psychologist and also member of the National Academy of Sciences, to which Richard Tolman was elected in 1923).

Following a suggestion from **Otto Stern**, Tolman began trying to apply the ideas of thermodynamics to the totality of a static universe. He quickly concluded that the observed ratio of helium to hydrogen could not have been achieved in equilibrium at any temperature. (The 1:3 ratio by mass observed is now understood as a product of the very nonequilibrium expansion of the early Universe.) By the time of his 1934 book, *Relativity, Thermodynamics, and Cosmology*, he had, of course, incorporated the evidence for an expanding universe presented in 1929 by **Edwin Hubble**. In 1935, Hubble and Tolman published a single joint paper on how one might use observations of the numbers of galaxies as a function of apparent brightness and of apparent brightness versus redshift as tests of whether the Universe would expand forever or be pulled back into contraction by the gravitational force of the total amount of matter. Tolman's own conclusion was that the data were not sufficient to make any reliable statement about the long-term behavior of the Universe, though he regarded the present expansion as well established. He took the possibility of an oscillating universe quite seriously.

Tolman considered a number of different ways of writing down equations to describe the behavior of space and time within general relativity. One of these proved to be particularly appropriate for the surroundings of a very compact object. In 1939, he made some progress in calculating the structure of such objects, and the almost simultaneous paper by **Julius Robert Oppenheimer** and his student **George Volkoff** successfully established the distribution of density and pressure expected inside a neutron star, if general relativity and quantum mechanics are the only relevant physics. The part common to these papers is generally called the Tolman–Oppenheimer–Volkoff equation of state.

In addition to his academy membership, Tolman received an honorary D.Sc. from Princeton University (1942) and was the 1932 J. Willard Gibbs Lecturer of the American Mathematical Society. His 1938 textbook on statistical mechanics remains in print and in use after 65 years.

George Gale

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Tombaugh, Clyde William

Born **Streator, Illinois, USA, 4 February 1906**
Died **Las Cruces, New Mexico, USA, 17 January 1997**

Clyde Tombaugh was the only person in the 20th century to discover an object classified as a major planet orbiting the Sun.

Tombaugh was the son of Muron and Della Tombaugh. The family moved to a farm near Burdett, Kansas in 1922 where Clyde attended high school. At the time of his death he was the only remaining staff member who had been present at Lowell Observatory, Flagstaff, Arizona, when Pluto was discovered.

At age 14, in a school assigned Autobiography, Tombaugh recounted his first experience observing the night sky with a telescope, when his uncle Leon Tombaugh showed him some stars and the planet Mars. He went on to say, "On New Year's Day [1919], my uncle gave me the telescope and said it was mine …. I was then the happiest boy in the world."

Tombaugh's early attempts at telescope making are documented in his letters to Napoleon Carreau, an optician from Wichita. Most enlightening are his comments in a 17 May 1926 letter to Carreau. He laments about problems, pointed out by Carreau, with an 8-in. mirror (his first) and explains in zealous detail about what he thinks are the reasons for its imperfect figure. Impressed with the quality of Tombaugh's subsequent work and attention to detail, Carreau later offered him a job.

At about the same time, Tombaugh sent his drawings of Mars and Jupiter to Lowell Observatory, where the director, **Vesto Slipher**, along with the trustee Roger Lowell Putnam, had decided to resume the late **Percival Lowell**'s search for Planet X. Tombaugh's letters and drawings captured the attention of the Lowell administrators, and they hired the young man, fresh from the farm in Kansas.

At Lowell Observatory in 1929, Tombaugh had the privilege of helping to bring a new telescope on line and developing an observing procedure for seeking a distant planet. The new instrument was the 13-in. Lawrence Lowell refractor named after the Harvard University president who financed the project. The lens, designed and partially finished by amateur astronomer **Joel Metcalf** before his death, arrived from Clark & Sons in January 1929, as did Tombaugh, who started work on 15 January. In a sense, Tombaugh and the telescope grew up together with Tombaugh helping to solve minor and major problems under the tutelage of Slipher, **Carl Lampland,** and Stanley Sykes.

Although Lowell had predicted a new planet based on orbital positions of Neptune and Uranus, Tombaugh's search had been underway for 10 months before he found the planet Pluto on plates exposed on 23 and 29 January and blinked on 18 February 1930. The discovery was announced on 13 March. Pluto was disappointingly faint, however. Various suggestions put forth at the time could not dispel the suspicion that its mass was far less than that assumed in Lowell's predictions.

The University of Kansas awarded Tombaugh the Edwin Emory Slosson 4-year Scholarship in 1931; he began his studies at Kansas in 1932. He would receive BA and MS degrees from Kansas in 1936 and 1939, and eventually an honorary D.Sc. from Northern Arizona State College in 1960.

Patricia Edson, her mother, and brothers James and Alden, moved to Lawrence, Kansas from Kansas City in 1932. Their house had several extra rooms, and brother James arranged to have Tombaugh move in as one of several boarders in the fall of 1933. Patricia enrolled at the University of Kansas that same fall as a philosophy major and, of course, met Tombaugh. They married at the end of the spring semester in 1934. That summer the couple drove to Flagstaff on the new Route 66. Daughter Annette was born in 1940 and son Alden in 1945.

After graduation from college, Clyde returned to Lowell and continued the search for other bodies in the outer Solar System. That photographic program, centered on the ecliptic, covered 70% of the celestial sphere. As Tombaugh pointed out, this study would have found planets brighter than magnitude 16.5, and, had there been an Earth-sized planet within 100 Astronomical Units, it would have been detected. Although the general public reveres a discovery, the null result from this systematic study is far more important. It has shaped the thinking of the astronomical community for more than 50 years, and it has influenced both our models of Solar System formation and our search for planetary systems around other stars. By-products of the study included the discovery of a cataclysmic variable (TV Corvis), six star clusters, two comets, observations of a number of asteroids and clusters of galaxies, and the discovery of one supercluster.

In 1943, Tombaugh was invited to teach physics and later navigation in a navy program at Arizona State Teacher's College (now the University of Northern Arizona). Toward the end of World War II the large number of veterans with delayed educations taxed US colleges. Clyde was contacted in 1944 by Fredrick Leonard at the

University of California at Los Angeles, and he spent a year teaching astronomy there. These activities interrupted his work in planetary astronomy, and when Tombaugh returned to Lowell hoping to continue, he found that he was out of a job!

James Edson facilitated Tombaugh's next move in 1946, helping him to launch his new career in rocket science at White Sands Proving Grounds in New Mexico. There, Tombaugh developed tracking systems to determine flight paths and rocket characteristics and helped establish the serious business of missile warfare.

Tombaugh returned briefly to Lowell in 1952. In a letter to Roger L. Putnam on 27 February 1952, he reports:

> In talking over several things, Dr. V. M. Slipher asked me if we could spend several weeks at the observatory this summer. He is desirous of repeating the 13-inch plates for [a] stellar proper motion survey, and wanted me to blink several pairs to ascertain what such a harvest would yield.

Although a brief survey was carried out in May 1952 with positive results, Tombaugh decided to stay in New Mexico, and the proper-motion study was completed by Henry Giclas.

From 1953 to 1958 Tombaugh directed a search for natural Earth-orbiting debris, and in 1955 he moved his operation to New Mexico State University [NMSU]. (This program was carried out initially at Lowell and later in Ecuador.) The telescope drive rate was adjusted to match the motion of objects orbiting at assumed distances from the Earth. Resulting exposures contained reference star trails and assured maximum exposure of faint sources. Again a systematic search yielded a null result. This time the result was welcome; near space was not hostile to manned activity.

At NMSU, Tombaugh assembled a team that provided systematic sets of planetary images that were used to support the Mariner, Viking, and Voyager missions. He was also instrumental in designing and obtaining funding for a 24-in. telescope for the university's Tortugas Mountain Observatory. It captured its first images in 1967, and carried out National Aeronautics and Space Administration [NASA] mission-supported research for almost 30 years. Bradford Smith, team member on the Mars Mariner and Viking missions, and principal investigator for the Voyager imaging team, began his career with Tombaugh's group.

In the mid-1960s, Tombaugh teamed up with two forward-thinking individuals on the NMSU campus. One was a recent aeronautical engineering/astronomy Ph.D. from the University of Arizona, W. L. Reitmeyer, and the other was research vice president William O'Donnell. Together they established a new Ph.D. granting Department of Astronomy in 1970.

From 1955 to retirement in 1973, Tombaugh taught geology and astronomy classes. His commitment was contagious, and his interest and dedication to public education did not flag as he entered retirement. Tombaugh continued to be a strong influence on students and made an amazing effort to satisfy the demands of the public. He came into his office regularly for 20 years after his retirement, providing never-to-be-forgotten experiences for students and faculty. In 1980, in collaboration with Patrick Moore, Tombaugh published his version of the discovery of Pluto, *Out of the Darkness: The Planet Pluto*. He also continued his interest in planetary astronomy, in particular NASA Mars projects and later, potential Pluto missions.

Reacting to lagging professional opportunities for young scientists, Clyde committed Patricia and himself to raising funds to establish the Clyde W. Tombaugh Fellowship at NMSU. Assisted by professor Bernard McNamara and biographer David Levy, he toured the United States and Canada from 1985 to 1990, presenting public lectures and raising funds in 53 locations in both countries.

Tombaugh published dozens of papers about the discovery of Pluto, research on observing techniques, and observations of planets, especially Mars and Jupiter. He also wrote hundreds of letters to lovers of astronomy of all ages.

Tombaugh received the Royal Astronomical Society Jackson-Gwilt medal in 1931. Other awards include the University of Kansas's Distinguished Service Citation in 1966 and Distinguished Public Service medals from NASA and the American Institute of Aeronautics and Astronautics, both in 1980. The Clyde W. Tombaugh Elementary School in Las Cruces proudly bears his name.

Tombaugh was a warm and stimulating friend who encouraged inventive thinking and perseverance. When he was not inflicting puns on his friends and colleagues, he was enthusiastically following new developments. Tombaugh was the only true "Plutocrat" of our time.

Books listed later by Hoyt and Levy provide the most outstanding and scholarly histories of the events before, during, and after the discovery. A detailed account of the natural Earth satellite search is given in the Final Technical Report, copies of which are available through the Rio Grande Historical Collections at NMSU. Information about Tombaugh's letters and other writings, including his age-14 autobiography, can be obtained from the same source at NMSU.

Herbert Beebe

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Torricelli, Evangelista

Born **Faenza, (Emilia-Romagna, Italy), 15 October 1608**
Died **Florence, (Italy), 25 October 1647**

Evangelista Torricelli is best known for his researches on geometry, hydrodynamics, and motion of weights. He was a pupil of **Benedetto Castelli**, who was in turn a former pupil of **Galileo Galilei**. Torricelli was able to express the principle of inertia in a clear and modern form: "When acting forces are absent, the motion is rectilinear with constant velocity." He observed Jupiter and noted the colored bands parallel to the Equator of the planet. His most important contribution to astronomy was his ability as a telescope maker, particularly for his excellent lenses. In a letter to Galilei, written on behalf of Castelli, he introduced himself saying that he had studied **Ptolemy**, **Tycho Brahe**, **Johannes Kepler**, and **Nicolaus Copernicus**, and his studies had convinced him to accept the Copernican system. He was the first in Rome to have made a careful study of Galilei's *Dialogo sopra i massimi sistemi*.

Margherita Hack

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Toscanelli dal Pozzo, Paolo

Born **Florence, (Italy), 1397**
Died **Florence, (Italy), May 1482**

Paolo Toscanelli's astronomical significance hinges primarily on his comet observations.

Toscanelli was the second son of Domenico, a physician, and Biagia Mei. His family was one of the richest medical families in Florence. Toscanelli never married and, apart from short periods of time he spent outside Florence, he lived in the household of his father and later of his brother and his nephews.

Our knowledge of Toscanelli's life and works is limited to a few documents, and his fame as one of the greatest personalities of the 15th century is mainly attested by the eulogies of his contemporaries. He was astronomer, mathematician, and physician, knew Greek, and owned an important collection of Greek and Latin manuscripts.

Nicholas Krebs (Nicholas of Cusa) reported he knew Toscanelli in Padua, where Nicholas attended the university from 1417 to 1424; therefore, we can argue that Toscanelli studied there in the same years. They remained in contact for life. Nicholas dedicated two mathematical works on the squaring of the circle to Toscanelli, and Toscanelli attended Nicholas at his deathbed in 1464. In 1425 he came back from Padua with his brother Piero, and they enrolled in the College of Florentine Physicians.

Two records testify to Toscanelli's public roles: In January 1442 he consulted about the construction of the dome of Florence Cathedral, Santa Maria del Fiore, and in September 1453 he consulted with the rulers of Florence as an astrologer. Toscanelli was a friend of famous artists like F. Brunelleschi and L. B. Alberti, and participated in the humanistic circles that flourished in Florence during the 15th century.

In Rome, Toscanelli also knew **Johann Müller** (Regiomontanus), who praised him as a mathematician and as an astronomer. In 1464, Müller reported that L. B. Alberti and Toscanelli made astronomical observations for the determination of the obliquity of the ecliptic.

Toscanelli was involved in the revival of the studies of geography and cartography and played an important role in the preparation of Christopher Columbus's voyages to America. He knew the Portuguese canon Fernao Martins in Florence and remained in contact with him after the latter's return to Lisbon. In 1474, Toscanelli sent Martins a letter describing a new route to the Far East, together with a map to clarify his theory. The letter and the map were later copied or directly sent to Columbus, inspiring his navigations.

Toscanelli was associated with the installation of the first meridian inside a church. A tradition states that it was made in 1468, but a document from 1475 recorded the payment for a gnomon to be installed in the lantern of Brunelleschi's dome in the Cathedral of Santa Maria del Fiore in Florence, to observe the Sun and determine the date of the summer solstice.

Toscanelli's only surviving works are contained in a few handwritten sheets discovered and published in the 19th century. There are notes and drawings on the observations of six comets, some mathematical computations, astronomical tables, lists of geographical places, a map grid, and two horoscopes.

The records of cometary observations are the most important of his surviving works. Toscanelli observed comet C/1433 R1 for 6 weeks, C/1449 Y1 for 7 weeks, 1P/1456 K1 (Halley) for a month, C/1457 A1 for several days, C/1457 L1 for 8 weeks, and C/1472 Y1 for nearly 3 weeks. In the 1890s, the Italian astronomer **Giovanni Celoria** was able to compute the orbital elements from an analysis of Toscanelli's documents. An evolution in his interests and his methods of representation of the observations has been indicated by J. Jervis after a more careful analysis of the manuscript. Initially in 1433, Toscanelli was most interested in the shape of the tail, probably to determine its astrological significance. In the observations of 1449/1450 he seemed more interested in a precise determination of the head of the comet, while in 1456, Toscanelli recorded the positions in longitude and latitude, suggesting he had begun to use an instrument like a torquetum or an armillary sphere. In 1472, probably due to his advanced age, he gave only verbal descriptions of cometary positions.

Toscanelli's notes represent the first example of observations of celestial phenomena over a long period of time, and of maps used as an integral part of precise measurements.

Giancarlo Truffa

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Tousey, Richard

Born **Somerville, Massachusetts, USA, 18 May 1908**
Died **Prince Georges County, Maryland, USA, 15 April 1997**

American space physicist Richard Tousey headed the group whose spectrograph, flown on a captured German V-2 rocket, made the first-ever detection of ultraviolet radiation (to which the atmosphere is opaque) from an astronomical object, the Sun. Tousey was the son of Coleman and Adella Richards (*neé* Hill) Tousey, and married Ruth Lowe in 1932. She died in 1994; they had one daughter.

Tousey earned an AB (*summa cum laude*, with election to Phi Beta Kappa) from Tufts University in 1928, and an AM (1929) and Ph.D. (1933) from Harvard University. The latter was completed with a thesis called "An Apparatus for the Measurement of Reflecting Powers with Application to Fluorite at 1216 Å" carried out under **Theodore Lyman**, discoverer of the 1216 Å "Lyman-α" line of hydrogen gas. Tousey held fellowships and a teaching position at Harvard (1929–1936) followed by a faculty position at Tufts University (1936–1941). He came to the Naval Research Laboratory [NRL] in 1941 at the invitation of its director of research **Edward Hulbert** and was soon head of the instrument section of the optics division, working on wartime optics-related research. Tousey became head of the micro-wave branch in 1945 and the rocket spectroscopy branch in 1958, retiring in 1978 but continuing to work on the spectrum of the Sun with Charles Brown and **Charlotte Moore Sitterly**.

Early in 1946, Tousey and his colleagues built a grating spectrograph suitable for use in captured German V2 rockets (replaced later with Aerobes). Not a single identifiable piece of the spectrograph could be retrieved from the first rocket's impact crater near White Sands, New Mexico. For the second try, the spectograph went into the rocket tail, flew on 10 October 1946, and returned the very first spectrum of solar radiation in the spectral region called the rocket ultraviolet. It was several years before they were able to push the sensitivity of their detectors far enough to record wavelengths as short as Lyman α, but about 1950, Tousey could say that he had found in the Sun the important hydrogen feature that his advisor had found in the laboratory. Meanwhile, another group, also within Hulbert's empire at NRL, developed an electronic detector for still shorter wavelengths, and the 1949 discovery of solar X-rays is largely associated with the name of **Herbert Friedman**, later also director of research at NRL.

Tousey's group also developed the first rocket-borne coronographs, permitting observations of the corona and study of its variability outside eclipses. Measurements of the ultraviolet absorption as the rockets rose and returned also provided the first determination of the vertical distribution of ozone in the Earth's atmosphere. Their detectors on the Orbiting Solar Observatory number 7 (1971–1974) discovered the phenomenon called coronal mass ejections, and recorded the sequence of events as material is blown off the Sun.

Tousey's greatest success in his own view was the design, building, and flying of two instruments that flew with astronauts on the Skylab mission for 4 months in 1974. One recorded extreme ultraviolet (170–630 Å) images with very high spatial resolution, showing rapid changes in the Sun's upper atmosphere, connected with sunspots, flares, and mass ejections. The other was a spectrograph with very good wavelength resolution. This led to the identification of a large number of features in the solar spectrum, and so to a better understanding of the temperature and density structure of the chromosphere and corona and of their compositions (which differ importantly from that of the optical photosphere). In support of this work, the laboratory also conducted a number of studies of the ultraviolet properties of optical materials. Nighttime rocket launches led to the first direct measurements of the nighttime airglow, which is reemission of solar energy stored in the gases of the upper atmosphere.

Tousey was elected to membership in the United States National Academy of Sciences (1960) and received its Henry Draper Medal (1963), along with medals, awards, and lectureships from astronomical and optical societies in the United States, Britain, and France. In addition to memberships in societies connected with spectroscopy, geophysics, astronomy, and physics, he was active in groups connected with his long-standing interests in birds (on which he coauthored a field list for the District of Columbia area), American silver, and music.

Eugene F. Milone

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Triesnecker, Franz [Francis] de Paula von

Born **Kirchberg, (Austria), 2 April 1745**
Died **Vienna, (Austria), 29 January 1817**

Franz de Paula von Triesnecker was well known in his times for his mathematical and astronomical skills that he used in his work to determine the exact location of many central European geographical positions. Triesnecker became a member of the Society of Jesus at the age of 16. He studied philosophy at Vienna and mathematics at Tyrnau. After teaching mathematics and philosophy at Jesuit institutions for a few years, Triesnecker entered the university at Graz to study theology and completed his doctorate of philosophy. He received his ordination soon after his graduation.

In 1782, Triesnecker was appointed as an assistant to **Miksa Höll** (Maximilian Hell), the director of the Imperial Observatory in Vienna. Triesnecker's duties included serving as an assistant editor of the *Ephemerides Astronomicae ad meridianem Vindobonensem* from 1782 until he became the editor in 1792. With the death of Hell in April 1792, Triesnecker was appointed director of the observatory. Triesnecker then served as both the editor on the annual ephemerides and as the director until his retirement in 1806. He shared editorial duties with his fellow Austrian astronomer Johann Tobias Bürg. Between the years 1787 and 1806, Triesnecker annually published his *Tabulae Mercurii, Martis, Veneris, Solares*, along with most of his micrometrical observations of the Moon, planets, Sun, and hundreds of stellar positions.

Triesnecker's numerous treatises deal mainly with astronomy and geography. In 1798, Triesnecker published an occultation table in the *Allgemeine Georgraphische Ephemerdin* giving the geographical position of the Buda Observatory (Ofen). The table was based on observations of two solar eclipses and his own observations of 12 stellar occultations by the Moon.

Triesnecker's major published works include: *Veränderliche Schicksate dreyer merkwürdiger Längenbestimmungen von Pekin, Amsterdam und Regensburg* (1802, 1804), *Astronomische Beobachtungen an verschiedenen Sternwarten von 1805 (–1815), herausgegeben von F. Triesnecker* (1805–1815), and *Über die Ungewissheit einiger astronomischen Fixpunkte bei der Entwerfung einer Karte von Persien und der asiatischen Türkey* (1802). Triesnecker's work also appeared in such publications as **János von Zach**'s *Monatliche Correspondenz zur Befoerderung der Erd- und-Himmels-Kunde*, **Johann Bode**'s *Astronomische Jahrbuch*, the *Commentarii Societatis Regiae Scientiarum Gottingensis*, and the *Transactions of the Royal Society of Bohemia*. In 1802, he published his monumental work on calculating the motions of the Moon in *Novae motuum lunarium tabulae*.

In geography Triesnecker determined or corrected the longitude and latitude of various places from the best available data. He completed Georg Ignaz von Metzburg's triangulation of lower Austria. Triesnecker's data formed the basis for the production of a new map of Austria, and assisted him with the triangulation of Galicia.

Triesnecker became a corresponding member of the Russian Academy of Sciences in Saint Petersburg on 5 February 1812. He was also a member of the scientific societies in Breslau, Göttingen, Munich, and Prague. Triesnecker was honored by the International Astronomical Union with the naming of a nearside lunar crater (latitude 4.°2 N, longitude 3.°6 E) in 1935 and a system of rilles, named Rimae Triesnecker, in 1964.

Robert A. Garfinkle

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Trouvelot, Étienne-Lêopold

Born **Guyencourt, Aisne, France, 26 December 1827**
Died **Meudon near Paris, France, 22 April 1895**

Étienne Trouvelot spent the busiest and most productive part of his life in the United States using the large refracting telescopes at Harvard College Observatory, the University of Virginia, and the United States Naval Observatory [USNO] to make original drawings of celestial phenomena. He published over 50 papers on astronomy, and made a huge number of evocative drawings of astronomical phenomena.

Little is known of Trouvelot's early life. It seems he dabbled in politics and had Republican tendencies. It is therefore possible he either fled or was exiled from France when Louis Napoleon rose to power after the *coup d'etat* of 1852. Whatever the situation, the events of that period are unconnected with astronomy.

Trouvelot immigrated to the United States, and in 1855 arrived in Massachusetts, supporting himself and his family as an artist. His leanings toward the natural sciences led him to join the Boston Natural History Society, and between 1868 and 1876 he contributed several papers on entomology to its publication. Trouvelot also became acquainted with Louis Agassiz. In 1860 he moved to Medhurst, a suburb of Boston, where he experimented in silkworm production. Not satisfied with the output of the native *Polyphemus* silkworm, Trouvelot went to Europe and sometime later in 1868 or early 1869 returned with eggs of the gypsy moth. Unfortunately, he either ignored or overlooked the possibility of accidental escape. The inevitable happened, and attempts to eradicate the consequent infestation proved ineffective; the subsequent defoliation of forests in the Northeastern United States is the fact for which Trouvelot is mainly ill-remembered.

Meanwhile, and perhaps fortunately, astronomy had caught Trouvelot's interest. In 1870 a number of quite spectacular auroral displays piqued his artistic sensibilities. His skillful renditions came to the notice of **Joseph Winlock**, director of the Harvard College Observatory, who in 1872 invited him to join the observatory staff. Observing regularly with the 15-in. refractor, Trouvelot produced numerous sketches for the series *Astronomical Engravings from the Observatory of Harvard College*, which comprised 35 plates, many in color.

In 1875, the year Trouvelot announced his discovery of veiled sunspots, he resolved to prepare a series of highly detailed drawings of celestial objects as they appear to experienced observers through large telescopes. Coincidentally that same year, he was offered the use of the USNO 26-in. Clark refractor. In September 1875 Trouvelot prepared an exquisite rendition of Saturn with the Washington instrument and started a magnificent drawing of the Great Nebula in Orion. In succeeding years he worked on a great number of drawings at various observatories including the 26-in. Clark refractor at the Leander McCormick Observatory of the University of Virginia. From those that were complete by 1876, Trouvelot selected 15 pastels as representative of his best work for display at the Philadelphia Centennial Exposition. The set, entitled *Astronomical Drawings*, was reproduced as chromolithographs and published in 1882. In 1878 he and his son George observed the total eclipse of the Sun on 29 July from Wyoming Territory.

In 1876, Trouvelot initiated the work with which his name will always be associated, a systematic study of the planets. In 1881 he published a major paper on Jupiter in the *Proceedings of the American Academy of Arts and Sciences*. In contributions to *The Observatory*, the *Comptes rendus* de l'Académie des Sciences, and *L'Astronomie*, Trouvelot considered aspects as diverse as white spots on Venus, the Great Red Spot of Jupiter, variations in the rings of Saturn, the apparent duplicity of the shadow of Jupiter's largest satellite Ganymede, various phenomena of Mars, and enigmatic appearances on the Moon. He also attempted, apparently unsuccessfully, to construct a lunar map 60 in. in diameter based on observations with a 6-in. refractor at Cambridge.

Trouvelot returned to France in 1882, and joined the leading solar expert **Pierre Janssen** at Meudon, Paris, where he indulged his fascination with the Sun. Trouvelot witnessed many spectacular prominences, including two massive eruptions in June 1885 (estimated to reach a height of 480,000 km) and another on 17 June 1891. He accompanied Janssen to the Caroline Islands to observe the total solar eclipse of 1883, and with **Johann Palisa** undertook a fruitless search for intramercurial planets. His last major publication, "Observations sur les Planètes Vénus et Mercure," communicated to the Société Astronomique de France in 1892, is perhaps his most important contribution. It is based on a twofold series of observations of the two planets, first at Cambridge, Massachusetts, 1876–1882, then at Meudon, 1882–1891, amounting to a total of 744 observations and 285 drawings. It is a landmark work of more than historical interest, and describes in great detail what the telescope reveals of these bodies.

Trouvelot was honored by the French Academy of Sciences with the award of their Valz Prize. A crater on the Moon is named in Trouvelot's honor.

Richard Baum

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Trumpler, Robert Julius

Born **Zürich, Switzerland, 2 October 1886**
Died **Oakland, California, USA, 10 September 1956**


Robert J. Trumpler

Swiss–American statistical and observational astronomer Robert Trumpler is best known as the person who, in 1930, provided definitive evidence for systematic absorption and scattering of starlight by dust in the plane of the Milky Way, settling an issue that had been debated for decades, not least by **Jacobus Kapteyn**. Trumpler also made important contributions to statistical astronomy, the study of the motions of the stars in the Milky Way.

Third of ten children in a large family of businessmen and manufacturers, Trumpler's early interest in business was transformed into a career in science after a short apprenticeship in a Zürich bank. In his student days he also was an alpinist and skier. After graduation from the Gymnasium first in his class, Trumpler entered the University of Zürich, later transferring to Göttingen University where he received the Ph.D. *magna cum laude* in 1910. A 1913 meeting of the Astronomische Gesellschaft in Hamburg provided opportunities to meet American astronomers, including **Frank Schlesinger**, who invited him to Allegheny Observatory. Though called for military service in 1914, Trumpler accepted the offered assistantship in 1915 and shortly thereafter traveled to the United States.

In 1919, Trumpler was invited to Lick Observatory and appointed assistant astronomer in 1920; the following year he became a naturalized United States citizen. Among his early observational projects, he made a photographic-visual survey of Mars at its opposition in 1924. His map of the planet sketched many of the features now more fully understood from later photographs. Trumpler also observed Eros at its opposition in 1931 as part of the campaign of the International Astronomical Union to measure the solar parallax.

In 1930, with the publication of his catalog of star clusters in his paper "Preliminary Results on Distances, Dimensions, and Distribution of Open Star Clusters," Trumpler showed that interstellar absorption was real; his meticulous observations enabled him to demonstrate its effects conclusively. His observations showed that the apparent linear diameters of more distant clusters of all types, based on their H–R diagrams, were larger than the diameters of nearby clusters of the same types. Trumpler's further analysis using diameters based on central concentrations and brightnesses gave the same results. However, this conclusion did not make sense physically. His meticulous observations and exhaustive analysis enabled him to eliminate the possibility that cluster diameters did increase with distance and conclude that the discrepancy was caused by interstellar absorption of about one magnitude per kilopersec, close to the modern value.

It took some years for the implications of Trumpler's work on absorption to be fully integrated into astronomical knowledge. He himself perceived the meaning as that both the Sun-centered Kapteyn universe and the very differently centered, larger galaxy of **Harlow Shapley** could be right. During World War II, **Henri Mineur** recalibrated the galactic-distance scale based on Cepheid variable stars using Trumpler's absorption, but the result did not diffuse out of France fast enough to prevent great surprise on the part of **Walter Baade** when he turned the new 200-in. telescope toward the Andromeda Galaxy and did not see the RR Lyrae stars in it, beginning about 1950. Great also was the surprise of most of the people who first heard about Trumpler's conclusion at the 1952 Rome General Assembly of the International Astronomical Union. Incorporating Trumpler's numbers roughly doubled the distances to external galaxies and so doubled the best estimate of the age of the Universe.

Trumpler had earlier contributed his remarkable observational skills to a test of **Albert Einstein**'s general theory of relativity. Einstein had predicted that starlight passing close to the Sun's limb would be bent by 1.745 arcsec. Trumpler assisted **William Campbell** (director of the Lick Observatory) during the total solar eclipse of 1922 at Wallal, Australia, observing many more stars than did earlier expeditions. They confirmed Einstein's prediction with a result of 1.75 arc sec (±0.09 arc sec), more accurate and confirmatory than previous observations.

In his early professional career while at the Swiss Geodetic Survey, Trumpler determined the longitudes of the Swiss observatories, and at Allegheny Observatory he published the parallaxes of several stars, the proper motion of Nova Aquila, and the relative motions of stars in the Pleiades. He also began a classification of star clusters that would later be the basis for his work in interstellar absorption. In his later career, with H. F. Weaver, Trumpler wrote the text *Statistical Astronomy*, which became a classic in the field.

Trumpler was an inspired teacher, fostering the development of many astronomers in his classes at the University of California at Berkeley. Even in retirement he continued to add to his catalog of clusters. His observations of certain O stars in clusters indicated anomalously high masses for some of them – data that have yet to be explained.

Trumpler served the American Astronomical Society as a councilor and the Astronomical Society of the Pacific as president in 1932 and 1949. The latter named its Trumpler Prize (given for an outstanding Ph.D. dissertation each year) for him. He was elected to the United States National Academy of Sciences (1932) and the American Academy of Arts and Sciences.

Katherine Haramundanis

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Tserasky [Tzeraskii], Vitol'd [Witold] Karlovich

Born **Sluck, (Belarus), 9 May 1849**
Died **Moscow, (Russia), 29 May 1925**

Vitol'd Tserasky was a prominent astronomer of Polish–Lithuanian descent who became director of the Moscow University Observatory (1890–1916). He was a pioneer in both the applications of photometry and photography to astronomical research. But due to the specific conditions of Tsarist Russia, Tserasky's ancestry led to complications in his scientific career.

Tserasky graduated from Moscow University in 1871, and after a number of successive appointments at the observatory, succeeded **Fedor Bredikhin** as director. Tserasky's doctoral dissertation (1887) was awarded for his construction of an apparatus (the Zöllner–Tserasky photometer) that employed an artificial star to permit the accurate measurement of starlight. In 1889, he was appointed professor of astronomy at Moscow University and taught there until his retirement in 1916. In 1914, Tserasky was elected a corresponding member of the Saint Petersburg Academy of Sciences.

Tserasky is chiefly remembered for his work in stellar and solar photometry, especially for an original measurement of the apparent stellar magnitude of the Sun (−26.5). He made the first determination of the lower limit of the Sun's surface temperature and is credited with the discovery of noctilucent clouds in the Earth's upper atmosphere. Among his preoccupations was the refinement of astronomical instruments.

At the Moscow Observatory, Tserasky's tenure as director began when all personnel "could be seated just on a single divan." Between 1891 and 1903, he performed numerous technical upgrades and completely refurbished the observatory with modern instruments (including a wide field, short-focus astrograph) for astrophysical research. This transition marked the beginning of the observatory's later growth and prosperity.

In 1895, Tserasky initiated a campaign for systematic photographic observations of variable stars. There, his wife Lydia Petrovna Tseraskaya (1855–1931) became an assistant and discovered 219 variable stars with the astrograph. Ultimately, this project created the foundation of the Moscow "glass library" of photographic plates. Continued by **Sergei Blazhko** and other Moscow astronomers, this plate collection is now among the richest in the world.

A crater on the Moon's farside has been named for Tserasky. In the former Soviet Union, however, his name was overshadowed by that of his successor, **Pavel Sternberg**, who was an active revolutionary.

Alexander A. Gurshtein

Alternate name

Ceraski, Vitol'd [Witold] Karlovich

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Tsu Ch'ung-Chih

➔ **Zu Chongzhi**

Ṭufayl

➔ **Ibn Ṭufayl: Abū Bakr Muḥammad ibn ʿAbd al-Malik ibn Muḥammad ibn Muḥammad ibn Ṭufayl al-Qaysī**

Turner, Herbert Hall

Born **Leeds, England, 13 August 1861**
Died **Stockholm, Sweden, 20 August 1930**

Besides making fundamental contributions to the disciplines of astronomy and seismology, Herbert Turner was a leading advocate of international cooperation in science. He was the eldest son of John and Isabella Turner. From Leeds Modern School and then Clifton College, Bristol, Turner won a scholarship to Trinity College, Cambridge, and matriculated there in 1879. In 1882, he finished as second wrangler in the finals of the mathematical *tripos*; the following year, he was awarded the Smith's Prize. After a year as fellow of his college, Turner became chief assistant at the Royal Greenwich Observatory (1884) directed by **William Christie**. He was elected a fellow of the Royal Astronomical Society in 1885 and a fellow of the Royal Society (London) in 1896. He served the British Association for the Advancement of Science as general secretary from 1913 to 1922, and received a number of British and foreign honorary degrees. In 1899, Turner married Agnes Whyte of Blackheath; they had one daughter. Both survived him.

At the Royal Observatory, Turner became heavily involved in planning the institution's contribution to the international *Carte du Ciel* Astrographic Chart and Catalogue Project, inaugurated in 1887. This massive undertaking, which was never fully completed, sought the cooperation of 18 worldwide observatories to exploit dry-plate photography for the purpose of producing a photographic map and positional catalog of all stars down to about 11th magnitude.

Turner was responsible for two crucial technical innovations. First, he devised a rectilinear coordinate system (the method of "standard coordinates") that made it possible to use simple linear equations to reduce a star's apparent to true position, while correcting for errors of position on the photographic plate. Turner's methodology allowed ordinary photography to replace that part of the traditional work in positional astronomy that had been conducted with meridian circle instruments. Turner's second technical innovation was the invention of an eyepiece scale for plate measurements. This made it possible to employ semiskilled labor in the plate reductions, which in turn enabled many smaller observatories to participate in the enterprise. Turner brought nearly a quarter of the Astrographic Catalogue to completion. These achievements were recognized by the award of the Bruce Gold Medal of the Astronomical Society of the Pacific in 1927.

In 1893, Turner was elected Savilian Professor of Astronomy at Oxford University, with a fellowship at New College. Turner was an obvious choice because his predecessor, **Charles Pritchard**, had already committed the University Observatory to the *Carte du Ciel*. A recently deceased benefactor enabled the observatory to acquire a 13-in. astrographic telescope (mounted in 1893), which served as its principal instrument.

During his lengthy career at Oxford, Turner became a leading figure in the Royal Astronomical Society, serving on its council for 43 years, as foreign secretary from 1919 to 1930, and its president from 1903 to 1905. Along with **John Dreyer**, Turner coedited the centennial *History of the Royal Astronomical Society* (1923) and furnished its chapter on the society's formative decade (1820–1830).

Turner traveled to the principal observatories in the United States and was especially well informed about developments in astrophysics. He was himself a keen observer of solar eclipses, although Oxford lacked the necessary resources to develop such research. The proximity of the privately owned Radcliffe Observatory, completely refurbished in 1902 with an 18/24-in. double refractor, made it impossible for Turner to obtain new equipment for his own observatory.

From his analysis of the results obtained by different observatories, Turner devised methods of deriving stellar magnitudes from the measured diameters of their images, and coined the term *parsec* to denote a distance corresponding to an angular measurement. In 1919, the new International Astronomical Union [IAU] elected Turner as president of the commission overseeing the Astrographic Catalogue. Yet, unable to secure further instrumental and other resources from his university for astronomy, he was increasingly drawn into the field of seismology.

One of Turner's professional characteristics was his belief that no good measurements should ever be lost to science. One consequence was that he brought the work of four British variable star observers to publication. Another of Turner's characteristics was an aptitude for identifying periodicities, and an evolving conviction that multidisciplinary studies might facilitate the deduction of physical processes in variable stars, terrestrial earthquakes, tides, and meteorology. He published tables that made it possible to use harmonic analysis to model stellar variability. These and related beliefs led Turner in 1913 to supervise the coordination and reform of his late friend John Milne's worldwide network of seismological reporting stations. The Royal Astronomical Society was already a forum for the emerging science of geophysics, and, in 1919, Turner became a prime mover in its Council's formation of a Geophysical Committee. In 1920, Turner was appointed its secretary while the IAU had likewise elected him as first president of its Commission on Seismology. Although seismology deflected Turner from astronomy after 1913 and especially after 1919, he knew that he had developed a unique resource.

In the history of seismology, Turner is remembered for four achievements: two of an administrative nature and two on a scientific/technical basis. His two administrative achievements were:

(1) that he kept Milne's international network for earthquake reporting in operation through World War I; and
(2) he effected the crucial transition to collating data by seismic *event*, rather than by reporting station, and this made useful analysis possible.

His first theoretical achievement was that he developed the Zoppritz–Turner tables for more successful locating of earthquakes. Using this refined tool, his discovery of deep-focus earthquakes in 1922 represented a great step forward. That same year, Turner founded the journal, *International Seismological Survey*, at the observatory, and had it accepted as the international publication of seismic events. Between 1919 and 1924, he was a leading promoter of broadcasting a world time service in order to facilitate the accurate correlation of earthquake reports. Turner was one of the first to suggest that the Earth had a liquid core, and his tables were the basis for Sir **Harold Jeffreys**'s and David Bullen's work that proved that hypothesis.

Turner's second technical achievement was that, through use of *International Seismological Survey* data, he was the first (in 1930) to map volcanic and earthquake events together as the "ring of fire" around the Pacific Rim. Turner innovated the way that seismology is done today, while the *International Seismological Survey* (now based at Newbury in Berkshire) and his discovery of deep-focus earthquakes are his legacy.

After 1902, a lobby to economize the observatory's budget (on account of the nearby Radcliffe Observatory) led to complex politics that Turner handled with insufficient care and increasing resentment. Through his achievements in seismology, and his tireless committee work, he managed to keep the increasingly obsolete observatory within the international front rank during a very difficult period for both sciences. Not an observer but a mathematician and a manager who believed in international cooperation to advance science, Turner was a big man with an outgoing personality who encouraged young and amateur talent better than he coped with university politics. But, overwork, and the worry caused by an over-stretched budget, along with attacks by a faculty colleague who sought to undermine Turner's new cooperation with the Radcliffe Observatory, led to a cerebral hemorrhage while presiding at an IAU meeting on seismology in Stockholm. He died in the Sabbatsberg Hospital.

Roger D. Hutchins

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Ṭūsī: Abū Jaʿfar Muḥammad ibn Muḥammad ibn al-Ḥasan Naṣīr al-Dīn al-Ṭūsī

Born **Ṭūs, (northeast Iran), 17 February 1201**
Died **Baghdad, (Iraq), 25 June 1274**

Naṣīr al-Dīn al-Ṭūsī's major scientific writings in astronomy, in which he worked to reform Ptolemaic theoretical astronomy, had an enormous influence upon late medieval Islamic astronomy as well as the work of early-modern European astronomers, including **Nicholas Copernicus.** Ṭūsī wrote over 150 works, in Arabic and Persian, that dealt with the ancient mathematical sciences, the

Greek philosophical tradition, and the religious sciences (law [*fiqh*], dialectical theology [*kalām*], and Sufism). He thereby acquired the honorific titles of *khwāja* (distinguished scholar and teacher), *ustādh al-bashar* (teacher of mankind), and *al-muʿallim al-thālith* (the third teacher, the first two being **Aristotle** and **Fārābī**). In addition, Ṭūsī was the director of the first major astronomical observatory, which was located in Marāgha (Iran).

Ṭūsī was born into a family of Imāmī (Twelver) Shīʿa. His education began first at home; both Ṭūsī's father and his uncles were scholars who encouraged him to pursue *al-ʿulūm al-sharʿiyya* (the Islamic religious sciences) as well as the *ʿulūm al-awā'il* (the rational sciences of the ancients). He studied the branches of philosophy (*ḥikma*) and especially mathematics in Ṭūs, but eventually traveled to Nīshāpūr (after 1213) in order to continue his education in the ancient sciences, medicine, and philosophy with several noted scholars; among the things he studied were the works of **Ibn Sīnā**, who became an important formative influence. Ṭūsī then traveled to Iraq where his studies included legal theory; in Mosul (sometime between 1223 and 1232), one of his teachers was Kamāl al-Dīn ibn Yūnus (died: 1242), a legal scholar who was also renowned for his expertise in astronomy and mathematics.

In the early 1230s, after completing his education, Ṭūsī found patrons at the Ismāʿīlī courts in eastern Iran; he eventually relocated to Alamūt, the Ismāʿīlī capital, and witnessed its fall to the Mongols in 1256. Ṭūsī then served under the Mongols as an advisor to Īlkhānid ruler Hūlāgū Khan, becoming court astrologer as well as minister of religious endowments (*awqāf*). One major outcome was that Ṭūsī oversaw the construction of an astronomical observatory and its instruments in Marāgha, the Mongol headquarters in Azerbaijan, and he became its first director. The Marāgha Observatory also comprised a library and school. It was one of the most ambitious scientific institutions established up to that time and may be considered the first full-scale observatory. It attracted many famous and talented scientists and students from the Islamic world and even from as far away as China. The observatory lasted only about 50 years, but its intellectual legacy would have repercussions from China to Europe for centuries to come. Indeed, it is said that **Ulugh Beg**'s childhood memory of visiting the remnants of the Marāgha Observatory as a youth contributed to his decision to build the Samarqand Observatory. Mughal observatories in India, such as those built by **Jai Singh** in the 18th century, clearly show the influence of these earlier observatories, and it has been suggested that **Tycho Brahe** might have been influenced by them as well. In 1274 Ṭūsī left Marāgha with a group of his students for Baghdad.

Ṭūsī's writings are both synthetic and original. His recensions (*taḥārīr*) of Greek and early Islamic scientific works, which included his original commentaries, became the standard in a variety of disciplines. These works included Euclid's *Elements*, **Ptolemy**'s *Almagest*, and the so called *mutawassiṭāt* (the "Intermediate Books" that were to be studied between Euclid's *Elements* and Ptolemy's *Almagest*) with treatises by Euclid, **Theodosius**, **Hypsicles**, **Autolycus**, **Aristarchus**, **Archimedes**, **Menelaus**, **Thābit ibn Qurra**, and the **Banū Mūsā**. In mathematics, Ṭūsī published a sophisticated "proof" of Euclid's parallels postulate that was important for the development of non-Euclidian geometry, and he treated trigonometry as a discipline independent of astronomy, which was in many ways similar to what was accomplished later in Europe by **Johonn Müller** (Regiomontanus). Other important and influential works include books on logic, ethics, and a famous commentary on a philosophical work of Ibn Sīnā.

In astronomy, Ṭūsī wrote several treatises on practical astronomy (*taqwīm*), instruments, astrology, and cosmography/theoretical astronomy (*ʿilm al-hay'a*). He also compiled a major astronomical handbook (in Persian) entitled *Zīj-i Īlkhānī* for his Mongol patrons in Marāgha. Virtually all these works were the subject of commentaries and supercommentaries, and many of his Persian works were translated into Arabic. They were influential for centuries, some still being used into the 20th century.

Ṭūsī's work in practical astronomy, as well as his *Zīj-i īlkhānī*, were not particularly original or innovative. This was not the case with his work in planetary theory. There he sought to rid the Ptolemaic system of its inconsistencies, in particular its violations of the fundamental principle of uniform circular motion in the heavens. Ṭūsī set forth an astronomical device (now known as the Ṭūsī-couple) that consisted of two circles, the smaller of which was internally tangent to the other that was twice as large. The smaller rotated twice as fast as the larger and in the opposite direction. Ṭūsī was able to prove that a given point on the smaller sphere would oscillate along a straight line. By incorporating this device into his lunar and planetary models, Ṭūsī reproduced Ptolemaic accuracy while preserving uniform circular motion. A second version of this couple could produce (approximately) oscillation on a great circle arc, allowing Ṭūsī to deal with irregularities in Ptolemy's latitude theories and lunar model.

These models were first found in Ṭūsī's Persian treatise *Ḥall-i mushkilāt-i Muʿīniyya* (Solution of the difficulties in the *Muʿīniyya*), written for his Ismāʿīlī patrons, and were further developed and incorporated years later in his famous Arabic work *al-Tadhkira fī ʿilm al-hay'a* (Memoir on astronomy), composed during his years with the Mongols. Ṭūsī's devices are of major significance for several reasons. First, they produced models that adhered to both physical and mathematical requirements; the two versions of the Ṭūsī couple, from the perspective of mathematical astronomy, allowed for a separation of the effect of distance of the planet from its speed (which had been tied together in the Ptolemaic models). Ṭūsī was thus able, for example, to circumvent Ptolemy's reliance on a circular motion to produce a rectilinear, latitudinal effect. Second, Ṭūsī's new models greatly encouraged and influenced the work of Islamic astronomers, such as his student **Quṭb al-Dīn al-Shīrāzī** and **Ibn al-Shāṭir** (14th century) as well as the work of early-modern European astronomers such as Copernicus. The Ṭūsī couple also appears in Sanskrit and Byzantine texts.

Ṭūsī also influenced his astronomical and cosmological successors with his discussion of the Earth's motion. Although he remained committed to a geocentric universe, Ṭūsī criticized Ptolemy's reliance on observational proofs to demonstrate the Earth's stasis, noting that such proofs were not decisive. Recent research has revealed a striking similarity between Ṭūsī's arguments and those of Copernicus.

Ṭūsī was committed to pursing knowledge in all its forms, and he tried to reconcile the intellectual traditions of late Greek Antiquity with his Islamic faith. As was the case with many Islamic scientists, he held that the certitude of the exact mathematical sciences, especially astronomy and pure mathematics, was a means toward understanding God's creation.

F. Jamil Ragep

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Tuttle, Horace Parnell

Born **Newfield, Maine, USA, 24 March 1839**
Died **Falls Church, Virginia, USA, 1893**

As colorful an assistant astronomer as any that have ever served at Harvard College Observatory [HCO], Horace Tuttle made independent discoveries of eight comets of which six bear his name, and discovered two asteroids.

The son of Moses and Mary (*née* Merrow) Tuttle of Newfield, Horace followed his older brother, Charles Wesley Tuttle (1829–1881) in taking an unpaid position at HCO in 1857. At the time, **William Bond** was still director of the observatory, and other members of the extraordinarily talented staff – paid or unpaid – included **George Bond**, **Asaph Hall**, and Sidney Coolidge.

While Charles Wesley Tuttle and Coolidge specialized in detailed observations of the Saturnian ring system, in part motivated by the effort to obtain data supporting Bond's theory of the fluid composition of the rings, Horace swept the skies for comets. In the year following his arrival at Harvard, Tuttle made independent discoveries of four comets, three of which bear his name. For this remarkable *fête*, Tuttle received, at the age of only 21, the Lalande Prize of the French Academie of Sciences. He also shared in the discovery of two of the most celebrated of all periodic comets: 109P/1862 O1 (Swift–Tuttle) and 55P/1865 Y1 (Tempel Tuttle), the parent comets of the Perseid and Leonid meteor showers, respectively. The period of comet 109P/Swift–Tuttle is 134 years, so that after its discovery during the Civil War, it was not seen again until 1992. It was then recovered by a Japanese amateur astronomer, Tsuruhiko Kiuchi. Its next return will not occur until 2126.

In addition to finding comets 55P and 109P, Tuttle discovered comets 8P/1858 L1 (Tuttle), 41P/1858 J1 (Tuttle–Giacobini–Kresák), C/1858 R1 (Tuttle), and C/1861 Y1 (Tuttle), and he made independent discoveries of C/1858 L1 (Donati), C/1859 G1 (Tempel), and the great comet C/1860 M1. Tuttle also discovered minor planets (66) Maja on 9 April 1861 and (73) Klytia on 7 April 1862.

Tuttle left Harvard in 1862 to join the Union army, serving with the 44th Massachusetts Infantry. His Harvard Observatory colleague Coolidge also joined the war effort, and would die in battle at Chickamauga. After 9 months in the infantry, Tuttle received an appointment as an accounting paymaster in the navy, and in 1864 made observations of comet C/1864 N1 (Tempel) from the deck of the ironclad *U. S. S. Catskill*. He played a role in the capture of the English blockade runner *Deer* shortly before the end of the war. After the war, Tuttle returned to Harvard and was awarded an honorary MA degree. It was during this return visit, in January 1866, that he independently identified 55P/1865 Y1 (Tempel–Tuttle), more than 3 weeks after it had first been located by **Ernst Tempel** at the Marseilles Observatory. This comet had actually been seen by Chinese astronomers as long ago as 1366, as noted by British comet orbit computer **John Hind**.

Unfortunately, Tuttle's descent was almost as rapid as his ascent. When the navy account books were audited after the war, a substantial shortfall was noted in Tuttle's figures. On one occasion, Tuttle was found to have illegally cashed a naval bill of exchange and claimed the lion's share had been stolen from him. He was eventually found guilty of embezzlement and "scandalous conduct tending to the destruction of good morals," and in 1875 was discharged from the navy. In spite of the cloud over his reputation, he returned to science in various roles for the United States Geographical and Geological Survey – among other things, he assisted in surveying the boundary between Wyoming and the Dakota Territory – and served for a time at the United States Naval Observatory, where in 1888, he independently discovered comet C/1888 U1 (the official credit for which went to **Edward Barnard** at the Lick Observatory). Certainly Tuttle never fulfilled his youthful promise. When he died he was forgotten and almost penniless and was laid to rest in a pauper's grave in Falls Church.

William Sheehan

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Tyrtamus

➔ **Theophrastus**

U

ˁUbaydī: Jalāl al-Dīn Faḍl Allāh al-ˁUbaydī

Died **1350**

There is little information about the identity and life of ˁUbaydī. According to a recorded note in one of his works, he was the student of **Quṭb al-Dīn al-Shīrāzī** (Istanbul, Süleymaniye, Nuri Efendi MS 149/2, 16b–81b). Since copies of his astronomical works are extant in Turkish manuscript libraries, it is assumed that he was educated, and that he studied in Anatolia.

ˁUbaydī's work represents a continuation of the tradition of studying mathematics and astronomy at the Marāgha School and Marāgha Observatory as well as ideas put forth by **Ibn al-Haytham**. He was particularly interested in *ˁilm al-hay'a* (theoretical astronomy) and wrote a commentary on **Maḥmūd al-Jaghmīnī**'s *al-Mulakhkhaṣ fī ˁilm al-hay'a al-basīṭa*. ˁUbaydī informs us in the preface that he wrote the commentary in 3 days at the request of some professors and students. There are at least 20 extant copies of the commentary in Turkish manuscript libraries.

ˁUbaydī wrote another important astronomical work, in February 1328, entitled *Bayān al-Tadhkira wa-tibyān al-tabṣira,* which was a commentary on **Naṣīr al-Dīn al-Ṭūsī**'s *al-Tadhkira fī ˁilm al-hay'a*. "*Al-tabṣira*" in the title refers to **Muḥammad al-Kharaqī**'s *al-Tabṣira fī ˁilm al-hay'a.* There are at least four extant copies of this work in Turkey.

One often finds copies of both works bound together; this was probably intentional since their contents complement one another. ˁUbaydī's two commentaries need to be examined more closely; only then will their place within the tradition of *ˁilm al-hay'a* be established. We do know, however, that ˁUbaydī's teaching of the subject in various schools certainly contributed toward making the tradition more widespread.

İhsan Fazlıoğlu

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Ulugh Beg: Muḥammad Ṭaraghāy ibn Shāhrukh ibn Tīmūr

Born **Sulṭāniyya, (Iran), 22 March 1394**
Died **near Samarqand, (Uzbekistan), 27 October 1449**

Ulugh Beg (Turkish for "great prince") was governor of Transoxiana and Turkestan and, during the last 2 years of his life, Timurid Sultan. However, he is mostly remembered as a patron of mathematics and astronomy. In Samarqand, he founded a school and the famous astronomical observatory, where the most extensive observations of planets and fixed stars at any Islamic observatory were made. Ulugh Beg is associated with a Persian astronomical handbook (*zīj*) that stands out for the accuracy with which its tables were computed.

Ulugh Beg was the first-born son of Shāhrukh (youngest son of the infamous conqueror Tīmūr or Tamerlane) and his first wife Gawharshād. He was raised at the court of his grandfather and, at the age of 10, was married to his cousin Agha Bīkī, whose mother was a direct descendent of Chingiz Khan. Thus Ulugh Beg could use the epithet Gūrgān, "royal son-in-law," which had originally been used for Chingiz's son-in-law.

In the years after Tīmūr's death in 1405, Ulugh Beg became governor of Turkestan and Transoxiana, the most important cities of which were the cultural centers Samarqand and Bukhara. Although not completely divorced from affairs of state, he is better known for his interest in religion, architecture, arts, and sciences, which were fostered by the Mongols as well as by the Timurids. Ulugh Beg is said to have spoken Arabic, Persian, Turkish, Mongolian, and some Chinese. He had a thorough knowledge of Arabic syntax and also wrote poetry. Although he honored Turkic–Mongolian customs, he also knew the Quran by heart, including commentaries and citations. Ulugh Beg was also a passionate hunter.

By 1411, Ulugh Beg had developed a lively interest in mathematics and astronomy, which may have been aroused by a visit in his childhood to the remnants of the Marāgha Observatory that had been directed by **Ṭūsī**. In 1417, he founded in Samarqand a *madrasa* (religious school or college) that can still be seen on the Registan Square. At this institution, unlike other *madrasas*, mathematics and astronomy were among the most important subjects taught. The most prominent teacher was **Qāḍīzāde al-Rūmī**, who was joined somewhat later by **Kāshī**.

Two extant letters by Kāshī to his father in Kāshān make clear that Ulugh Beg was personally involved in the appointment of scholars and that he was frequently present, and actively participated, in seminars, where he displayed a good knowledge of mathematical and astronomical topics. Kāshī relates how Ulugh Beg performed complicated astronomical calculations while riding on horseback. Anecdotes from other sources show that Ulugh Beg, like many other Muslim rulers, believed in astrology and fortune-telling. He appears as a person who very much respected the scholars he appointed, and whose main objective was to reach scientific truth.

In 1420, Ulugh Beg founded his famous astronomical observatory on a rocky hill outside the city of Samarqand. Its circular main building, beautifully decorated with glazed tiles and marble plates, had a diameter of about 46 m and three stories reaching a height of approximately 30 m above ground level. The north–south axis of the main building was occupied by a huge sextant with a radius of 40 m (called Fakhrī sextant after that of **Khujandī**). On the scale of this instrument, which partially lay in an underground slit with a width of half a meter, 70 cm corresponded to 1° of arc, so that the solar position could be read off with a precision of 5″. On the flat roof of the main building various smaller instruments could be placed, such as an armillary sphere, a parallactic ruler, and a triquetrum. Among other instruments known to have been used in Samarqand are astrolabes, quadrants, and sine and versed sine instruments.

Although Ulugh Beg was the director of the Samarqand Observatory, Kāshī was in charge of observations until his death in 1429, after which he was succeeded by Qāḍīzāde, who died after 1440. The observational program was completed by **Qūshjī**, who had studied in Kirmān (southeastern Iran) before returning to Samarqand. The results of the observations made under Ulugh Beg include the measurement of the obliquity of the ecliptic as 23° 30′17″ (the actual value at the time was 23° 30′48″) and that of the latitude of Samarqand as 39° 37′33″ N. (modern value: 39° 40′). Furthermore, most of the planetary eccentricities and epicyclic radii were newly determined, and the longitudes and latitudes of the more than 1,000 stars in **Ptolemy**'s star catalogue were verified and corrected. Precession was found to amount to 51.4″ per year (corresponding to 1° in little more than 70 years; the actual value is 50.2″ per year).

The observatory of Ulugh Beg stayed in operation for little more than 30 years. It was finally destroyed in the 16th century and completely covered by earth in the course of time. In 1908, archaeologist V. L. Vyatkin recovered the underground part of the Fakhrī sextant, consisting of two parallel walls faced with marble and the section of the scale between 80° and 57° of solar altitude. Ulugh Beg's observatory exerted a large influence on the huge masonry instruments built by **Jai Singh** in five Indian cities (most importantly Jaipur and Delhi) in the 18th century, more than 100 years after the invention of the telescope.

The main work with which Ulugh Beg is associated is an astronomical handbook with tables in Persian, variously called *Zīj-i Ulugh Beg*, *Zīj-i Jadīd-i Sulṭānī*, or *Zīj-i Gūrgānī*. In the introduction, Ulugh Beg acknowledges the collaboration of Qāḍīzāde, Kāshī, and Qūshjī, who were undoubtedly responsible for the underlying observations as well as the computation of the tables. The *Zīj* is in many respects a standard Ptolemaic work without any adjustments to the planetary models. It consists of four chapters dealing with chronology, trigonometry and spherical astronomy, planetary positions, and astrology, respectively. The instructions for the use of the tables, which were edited and translated into French by L. Sédillot in the middle of the 19th century, are clear but very brief and do not even include examples of the various calculations.

Thus, the most significant part of Ulugh Beg's *Zīj* lies in the observations and computations underlying the tables. Most impressively, the sine table, covering 18 pages in the manuscript copies, displays the sine to five sexagesimal places (corresponding to nine decimals) for every arc minute from 0° to 87° and to six sexagesimal places (11 decimals) between 87° and 90°. All independently calculated values for multiples of 5′ are correct to the precision given, whereas the intermediate values, calculated by means of quadratic interpolation, contain incidental errors of at most two units. Also most of the planetary tables in the *Zīj* were calculated to a higher precision than before. New types of tables were added that simplified the calculation of planetary positions. Ulugh Beg's star catalog for the year 1437 represents the only large-scale observations of star coordinates made in the Islamic realm in the medieval period. (Most other catalogs simply adjusted Ptolemy's ecliptic coordinates for precession or were limited to a relatively small number of stars.)

Ulugh Beg's *Zīj* was highly influential and continued to be used in the Islamic world until the 19th century. It was soon translated into Arabic by Yaḥyā ibn ʿAlī al-Rifāʿī and into Turkish by ʿAbd al-Raḥmān ʿUthmān. Reworkings for various localities were made in Persian, Arabic, and Hebrew by scholars such as ʿImād al-Dīn ibn Jamāl al-Bukhārī (Bukhara), **Ibn Abī al-Fatḥ al-Ṣūfī** (Cairo), Mullā Chānd ibn Bahāʾ al-Dīn and Farīd al-Dīn al-Dihlawī (both Delhi), and Sanjaq Dār and Husayn Qusʿa (Tunis). Commentaries to the *Zīj* were written by Qūshjī, **Mīram Chelebī**, **Bīrjandī**, and many others. Hundreds of manuscript copies of the Persian original of Ulugh Beg's *Zīj* are extant in libraries all over the world. Already in 17th-century England, various parts of the *Zīj* were published in edition and/or translation.

Little is known about other works of Ulugh Beg. A marginal note by him in the India Office manuscript of Kāshī's *Khāqānī Zīj* presents a clever improvement of a spherical astronomical calculation. A *Risāla fī istikhrāj jayb daraja wāḥida* (Treatise on the extraction of the sine of 1°) has been attributed to Ulugh Beg on the basis of a citation in Bīrjandī, although most manuscripts of this work mention Qāḍīzāde as the author. Aligarh Muslim University Library lists a treatise *Risāla-yi Ulugh Beg* that is yet to be inspected. Finally, an astrolabe now preserved in Copenhagen and made in 1426/1427 by Muḥammad ibn Jaʿfar al-Kirmānī, who is known to have worked at the observatory in Samarqand, was originally dedicated to Ulugh Beg.

In 1447, Ulugh Beg succeeded his father Shāhrukh as sultan of the Timurid empire. However, he was killed on the order of his son ˁAbd al-Laṭīf. An investigation of Tīmūr's mausoleum by Soviet scholars in the 1940s showed that Ulugh Beg was buried as a martyr in accordance with *Sharīˁa* (Islamic law), *i. e.*, fully clothed in a sarcophagus.

Benno van Dalen

Alternate name

Gūrgān

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Umawī: Abū ˁAlī al-Ḥasan ibn ˁAlī ibn Khalaf al-Umawī

Born **Cordova, (Spain), 1120**
Died **Seville, (Spain), 1205/1206**

Abū al-Ḥasan al-Umawī, known as al-Khaṭīb (the preacher), was an expert in the Islamic religious sciences and the Arabic language. He wrote a number of treatises among which there are two on Arabic ethnoastronomy: *Kitāb al-Lu'lu' al-manẓūm fī ma ˁrifat al-awqāt bi-'l-nujūm* (Book of the pearl in the necklace on the knowledge of time by means of the stars) and *Kitāb al-Anwā'* (Book about the *Anwā'*). The book belongs to a genre that aims to compile astronomical and meteorological materials from traditional Arabic lore inside the framework of the *anwā'*, periods of 13 days defined by the risings and settings of certain asterisms (lunar mansions) located along the lunar ecliptic, which account for the complete solar year. Umawī's main source is the *Kitāb al-Anwā' wa-'l azmina* by another Cordovan, Ibn ˁĀṣim (died: 1013), who had compiled materials taken from philologists of eastern Islam from the 8th century onward.

As a religious scholar, Umawī expanded on and completed Ibn ˁĀṣim's chapters on the procedures of Arabic folk astronomy that could help determine the times of prayers (*mīqāt*) or find the direction of Mecca (*qibla*). The treatise contains a method for determining night hours based upon the appearance of the asterisms of the *anwā'* system – this chapter seems to be related with Umawī's other astronomical treatise mentioned above, two series of lengths of shadows cast by a gnomon to determine prayer times (one of them written in a numerical notation, the *Rūmī* ciphers, found only in Andalusia and north Africa), and a long fragment on the possibility of observing Canopus (*Suhayl*) from Muslim Spain, a star used to determine the direction of Mecca. The author seems to be aware of more sophisticated forms of astronomy as he mentions two unusual sundials, the *mīzān fazārī* and the *mukḥula*.

There are two possible reasons for Umawī's interest in continuing a tradition that by his time was two centuries old: First, the rulers of the period, the Almohads, used to train their sons in the observation of the asterisms of the *anwā'* system; and second, the Almohad mosques, unlike those built by their predecessors, the Almoravids, were often directed toward the rising of Canopus. About a century later, this treatise was used by the famous Moroccan astronomer **Ibn al-Bannā'** as a source for his *Kitāb fī al-anwā'* (Book on the *anwā'*). Only the second treatise has come down to us, albeit in fragmentary form (preserved in El Escorial Library, MS 941).

Miquel Forcada

Alternate name

al-Khatīb al-Umawī al-Qurṭubī

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Unsöld, Albrecht

Born **Bolheim near Tübingen, (Baden-Württenberg), Germany, 20 April 1905**
Died **Kiel, Germany, 23 September 1995**

German stellar astrophysicist Albrecht Unsöld made major theoretical and observational contributions to the detailed analysis of stellar spectra resulting in accurate measurements of temperatures, densities, and compositions of the Sun and stars. He was the son of a minister, and had begun reading and writing about atomic physics as early as age 14 when he sent a manuscript to Arnold Summerfeld in Munich, Germany. Unsöld received enough encouragement that he left the University of Tübingen very shortly after Gymnasium to study in Munich, where he received a Ph.D. in 1927 with a thesis on quantum mechanics of atomic structure carried out under Summerfeld. His own students in due course included a number of other German stellar astrophysicists holding university professorships: Karl-Heinz Bohm, Kurt Hunger, Gerhard Traving, Volker Weidemann, Bodo Baschek, and Dieter Reimers. He married Dr. Liselotte Kuhnert, a biologist, in 1934, and they had four children.

After brief stays at Potsdam Observatory, Munich, Mount Wilson Observatory (1928–1929 on a Rockefeller Fellowship), and Hamburg University (1930–1932), Unsöld was appointed professor at Kiel University (the youngest such appointment recorded in Germany) in 1932 and remained there for the rest of his career, officially retiring in 1973 but remaining active in the astronomical community until the death of his wife in 1990. He obtained his *Habilitation* from Munich in 1929 with a paper interpreting the Balmer hydrogen lines in the solar spectrum.

Specific contributions to the analysis of conditions in the Sun and stars included the recognition that absorption lines are broadened by thermal Doppler effects, the Stark effect, the close approach of atoms to each other, and the natural lifetimes of the excited states. This enabled Unsöld to combine strong and weak lines of a given element to learn the temperature of the layers producing the lines and the total number of atoms responsible, hence the abundance of that element. He was also a pioneer in understanding the relationship between convection in the solar atmosphere and the granulation of the level we see. His 1937 monograph *Physics of Stellar Atmospheres* made his methods available to the entire community, where they were widely used.

A fortunate visit to McDonald Observatory enabled Unsöld to take some high-resolution stellar spectra in 1939, which provided material for him and his students to work on during World War II. Unsöld and his close friend and colleague W. Lochte-Holtgreven, a plasma physicist, were drafted to work on meteorology during the war. Proximity to Kiel enabled Unsöld to save the library of **Heinrich Schumacher** (founder of the oldest astronomical journal, *Astronomische Nachrichten*) when the observatory buildings were bombed.

Unsöld edited the main West German publication in the field, *Zeitschrift für Astrophysik*, until its 1969 merger with other European journals to form *Astronomy and Astrophysics*. He had, as it happened, written the first paper ever published in the *Zeitschrift* (founded in 1930).

After the war, Unsöld became the first dean of the faculty in the reopened University of Kiel and later served as rector. He opened a small radio astronomy observatory in connection with the optical observatory and continued to collaborate with students on theory of stellar atmospheres. The second 1955 edition of *Physics of Stellar Atmospheres* included many of the new developments like mixing-length theory and model atmospheres obtained by numerical methods. His 1967 text *Der Neue Kosmos* was intended to hark back to **Alexander von Humboldt**'s *Kosmos* of 1859 and to introduce a new generation to modern astrophysics.

Unsöld's own scientific interests broadened to include the origin of the chemical elements as well as their abundances in the Sun and stars, and at this point he began to diverge from the majority of the community. He was not convinced that synthesis in stars was important, and instead favored bulk production in "little bangs" at the beginning of galactic history. His last book in 1981 on evolution dealt not just with cosmology and biology, but also with psychology, art, and religion.

Unsöld received honorary degrees from Utrecht, Edinburgh, and Munich universities as well as the Bruce Medal of the Astronomical Society of the Pacific, a Gold Medal and the Darwin Lectureship of the Royal Astronomical Society (London), and memberships in a number of honorary organizations. He was both a violinist and a painter in watercolors, continuing these beyond the time he ceased interacting with other scientists.

Christian Theis

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ˁUrḍī: Mu’ayyad (al-Milla wa-) al-Dīn (Mu’ayyad ibn Barīk [Burayk]) al-ˁUrḍī (al-ˁĀmirī al-Dimashqī)

Born **probably ˁUrḍ between Palmyra and Ruṣāfa, (Syria), *circa* 1200**
Died **Marāgha, (Iran), *circa* 1266**

ˁUrḍī was one of the major figures of Islamic astronomy in the 13th century, and participated in a number of important scientific innovations and developments. Sometime before 1239, ˁUrḍī moved to Damascus, where he worked as an engineer, a teacher of geometry. and, possibly, of astronomy as well. In 1252/1253, as he says in his *Risālat al-Raṣd*, he built the socalled perfect instrument for al-Malik al-Manṣūr, Lord of Ḥimṣ. In the 1250s **Naṣīr al-Dīn al-Ṭūsī** asked him to come to Marāgha in Azerbaijān (now in northwest Iran) to help in the building of an observatory under the patronage of the Mongol ruler Hülegü. The observatory, one of the most important ever built in the Islamic world and arguably the first full-scale observatory in the modern sense, was founded in 1259, and ˁUrḍī arrived in Marāgha in that year (or shortly before). He took part in building the observatory outside the city and erected special devices and water wheels to raise the water to the observatory hill; he also participated in the construction of a mosque and a special building for Hülegü’s residence. At the observatory in Marāgha, ˁUrḍī probably joined in the observations for Ṭūsī’s *Īlkhānī Zīj* and was mentioned in this treatise. Though a noted astronomer and instrument maker, his participation in the observatory was limited to its early years, in as much as he constructed instruments there only before 1261/1262. Several instruments for which ˁUrḍī tells us he prepared models were actually seen by later visitors, further suggesting that he was not the only instrument maker at Marāgha. His son Muḥammad, also a member of the observatory staff, made a copy of his father’s *Kitāb al-Hay’a* and constructed a celestial globe, now preserved in Dresden, which was used at the observatory. ˁUrḍī, as well as Ṭūsī, was a member of the so called School of Marāgha, which also included **Quṭb al-Dīn al-Shīrāzi** and a number of other astronomers.

Urḍī’s *Risāla fī Kayfiyyat al-arṣād* (or simply *Risālat al-Raṣd*) is a rich and informative treatise on observational instruments, preserved in a unique manuscript in Paris. Some of the instruments mentioned in this treatise were well known, others were invented by ˁUrḍī himself. The treatise mentions the instruments built before and up to 1261/1262. The introduction describes the determination of the meridian by means of an “Indian circle.” ˁUrḍī tells us the place and time of the erection of the instruments, and he also outlines his relationship to Ṭūsī. The following instruments are mentioned: a mural quadrant, that seems to be used in general for altitude measurement, as well as for a careful determination of the latitude of Marāgha and the obliquity of the ecliptic; an armillary sphere for the measurement of the ecliptic longitude and latitude; a solstitial armilla for the determination of the obliquity of the ecliptic; an equinoctial armilla for the determination of the entry of the Sun into the equatorial plane and the path of the Sun at the equinoxes; a so called dioptrical ruler of **Hipparchus** for the measurements of the apparent diameters of the Sun and the Moon and the observation of eclipses; an azimuth ring for the determination of the altitude and the azimuth; and several other rulers and instruments, such as the “perfect instrument” for the measurement of the azimuth. ˁUrḍī ends with a critique of the parallactical ruler described by **Ptolemy**. As for the size of the instruments, ˁUrḍī remarks that the instruments should be as large as possible to have the required division of the scales.

ˁUrḍī’s *Kitāb al-Hay’a*, written sometime before ˁUrḍī reached Marāgha in 1259, is a work on theoretical astronomy that includes a critique of Ptolemy’s *Almagest* and his *Planetary Hypotheses*. There exist two versions of ˁUrḍī’s treatise: an earlier one compiled sometime between 1235 and 1245 and a later version in which he edited whole chapters of his original text to make the arguments more consistent. In the *Kitāb al-Hay’a* ˁUrḍī introduces the reader to Ptolemaic astronomy and then explains the difficulties arising from some of Ptolemy’s methods and techniques. He then presents his own astronomical models as an alternative. For ˁUrḍī, as well as for other astronomers of the so called School of Marāgha, the main problem in Ptolemaic astronomy was the lack of consistency between the mathematical models and the principles of natural philosophy. Examples occurred in the prosneusis point for the Moon, the deferent in the lunar model, the equant in the model for the superior planets, the inconsistencies in the planetary distances, and the inclination and deviation of the spheres of Mercury and Venus that were meant to account for latitude. In ˁUrḍī’s opinion, these inconsistencies violated the essential consistency between the theoretical mathematical models and the accepted natural and physical axioms. ˁUrḍī held to the basic principles of Greek astronomy, especially the circular and uniform motion of the heavenly bodies, and the Earth as the unmovable center of the Universe; he also appreciated the validity of the Ptolemaic planetary observations as quoted in the *Almagest*. But he objected to the mathematical models that Ptolemy had devised to describe the motions of the planets. ˁUrḍī tried to find astronomical models that would preserve Ptolemy’s observations, and which would also be consistent mathematically as well as physically. To this end, he devised the ˁUrḍī lemma, a developed form of the theorem by **Apollonius** that transformed eccentric models into epicyclic ones. ˁUrḍī stated that if we construct two equal lines on the same side of any straight line so that they make two equal angles with that straight line, be they corresponding or interior, and if their endpoints are connected, then the line resulting from connecting them will be parallel to the line upon which they were erected (*Kitāb al-Hay’a*, p. 220). The new technique of bisecting the Ptolemaic eccentricity allowed him to preserve Ptolemy’s deferent, while preserving the uniform, circular motions of the celestial orbs that revolve on their own centers, thus avoiding the apparent contradictions in Ptolemy’s model. ˁUrḍī’s *Kitāb al-Hay’a* was written within a tradition of astronomical literature that was critical of Ptolemy, but it apparently did not depend upon the work of Ṭūsī, who also presented alternative models in several of his works (many of which were based upon the Ṭūsī couple that transforms circular motion into linear motion). ˁUrḍī's work was quoted by **Ibn al-Shāṭir**, and influenced **Bar Hebraeus** and Quṭb al-Dīn al-Shīrāzī. Furthermore, there are many similarities to **Nicholaus Copernicus**'s work. ˁUrḍī's technical alternative to Ptolemy's model for the upper planets is essentially the same as that in Copernicus's *De revolutionibus*.

ˁUrḍī also wrote some minor treatises: a commentary on **Kharaqī**'s astronomical treatise *Kitāb al-Tabṣira fī ˁilm al-hay'a*, that closely follows Kharaqī's wording (extant in a unique manuscript in Madrid); a supplement to a problem in the *Almagest*, probably preserved in Mashhad and Ankara; a short treatise on the determination of the solar eccentricity, preserved in Ankara and Istanbul; and a *Risālat al-ˁAmal fī al-kura al-kāmila* on the armillary sphere, mentioned in ˁUrḍī's *Risālat al-Raṣd* as well as in his *Kitāb al-Hay'a*, which seems no longer extant. In addition, ˁUrḍī himself, or his son, copied in 1252/1253 the recension of the *Almagest* by Ṭūsī, which is preserved in Cairo.

Both of ˁUrḍī's main works, the *Risālat al-Raṣd* and the *Kitāb al-Hay'a*, are characterized by improvement and refinement. On the one hand, he tried to make precise instruments – some standard, others of his own invention – that would result in the best observations possible. The *Risālat al-Raṣd* gives the reader a rare insight into the equipment of a medieval Islamic observatory. On the other hand, he attempted to make the Ptolemaic astronomy more consistent by developing new and highly sophisticated planetary theories, some of them mathematically identical to Copernicus's non-Ptolemaic models.

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Urey, Harold Clayton

Born **Walkerton, Indiana, USA, 29 April 1893**
Died **San Diego County, California, USA, 5 January 1981**

American chemist Harold C. Urey received the 1934 Nobel Prize in Chemistry for his discovery of heavy hydrogen (deuterium), which proved to be of enormous importance in understanding both energy generation in the Sun and stars and conditions in the early Universe, where all the deuterium that exists today was produced. Astronomers also remember him for a definitive table of the abundances of the elements, compiled in collaboration with **Hans Suess**, which guided the modern understanding of nucleosynthesis in stars. (See **William Fowler** and **Fred Hoyle**.) In addition, Urey suggested a way of imitating atmospheric conditions of the early Earth with a laboratory experiment, carried out in 1953 by Stanley Miller (but called a Urey atmosphere experiment), which demonstrated that simple molecules like methane, ammonia, and water could form amino acids and other biologically important molecules under natural conditions.

Urey was the son of Reverend Samuel Clayton Urey and entered the University of Montana in 1914, receiving a BS in zoology in 1917. After a few years work at Barrett Chemical Company in Maryland and as an instructor at the University of Montana, he entered graduate school at the University of California (Berkeley) in 1921, receiving a Ph.D. in chemistry in 1923 for work with Gilbert Newton Lewis. Urey spent the following year at **Niel Bohr**'s Institute in Copenhagen on a Scandinavian–American fellowship. During and after his stay in Copenhagen, he held a research associateship at Johns Hopkins University (1924–1929). Urey was appointed associate professor of chemistry at Columbia University, moving up to professor in 1934, and serving as executive officer of his department from 1939 to 1942. During the war years Urey also directed a Columbia laboratory connected with the atomic bomb project.

Urey moved to a professorship at the Institute of Nuclear Studies at the University of Chicago in 1952 and held the Ryerson Professorship there from 1952 to 1958. During his Columbia and Chicago years he also spent various periods as visiting professor or endowed lecturer in England, Israel, and at a number of American universities, and was editor of the *Journal of Chemical Physics* from 1933 to 1940. On reaching normal retirement age, Urey was appointed to one of the first professorships-at-large at the University of California [UC], meaning that his tenure resided across the whole system. He chose, however, to locate at the relatively new UC San Diego campus in La Jolla. Quite remarkably for one of his distinction, Urey enjoyed teaching introductory chemistry, and his department recalled him to active duty to do so long after his official retirement, indeed until a few years before his death, when he could no longer easily climb the steps to the lecture room podium.

Urey's early research at Columbia concerned absorption spectra and structure of molecules. In 1931 he devised a method for evaporating a large quantity of liquid hydrogen down to a milliliter, which would automatically concentrate any heavy component (the lighter atoms or molecules tend to evaporate more easily), at a time when the concept of an isotope was fairly new. This led to the discovery of deuterium. He and E. W. Washburn evolved the electrolytic method for isotope separation, and Urey was able to investigate the properties of deuterium and measure its abundance, which he found to be about 2 parts in 10,000 in ordinary water.

In his postwar career in Chicago, Urey turned almost fully to geochemistry and cosmochemistry. His work with the heavy isotope oxygen-18 enabled him to devise a method for estimating ocean temperatures as far back as 180 million years ago. Again, light things evaporate more easily, so the ratio of O^{18} to O^{16} in fossil seashells is an indicator of the water temperature in which they lived. The isotope work in turn led Urey to the study of the relative abundances of the chemical elements on Earth and in meteorites and toward the development of a theory of the formation of the elements in stars, put forward soon after by E. Margaret Burbidge, Geoffrey R. Burbidge, Fowler, and Hoyle (as well as by Alastair G. W. Cameron in Canada). Consideration of the compositions of the Earth's early atmosphere and its implications for the origin of life was also a product of his Chicago years.

After 1958, Urey became a scientific advisor to the space program. One of his conclusions was that billions of years of impacts of small meteorites on the surface of the Moon, chipping off bits from the lunar rocks, would probably have covered the lunar surface with a thick layer of quicksand-like dust, a major hazard for any landing on the surface. Luckily this proved not to be the case. Thomas Gold of Cornell University was right in his expectation that the dust would be firmly compacted and able to support both spacecraft and astronauts, while taking clear impressions of landing gear and boots.

Urey's major books include *Atoms*, *Molecules and Quanta* (two volumes, 1930) with Arthur E. Ruark; *The Planets, Their Origin and Development* (1952); and *Isotopes and Cosmic Chemistry* (1962) with H. Craig, G. L. Miller, and Gerald J. Wasserburg.

In addition to the Nobel Prize, Urey was the recipient of 23 honorary degrees from universities stretched across the United States and Europe, from Athens to Wayne State. He was awarded medals and other prizes by the Franklin Institute, the University of Paris, the United States government (National Medal of Science), the United States National Academy of Sciences, the American Chemical Society, and the Royal Astronomical Society (London), among others. Urey was elected to honorary membership in scientific academies in Belgium, Portugal, Great Britain, India, Ireland, France, and Sweden. He married in 1936, and he and his wife had four children, one of whom, John Clayton Urey, is a biochemical geneticist.

Fathi Habashi

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ˁUṭārid: ˁUṭārid ibn Muḥammad al-Ḥāsib

Flourished **9th century**

ˁUṭārid ibn Muḥammad is sometimes also referred to as al-Kātib (the scribe), but the usual appellation, al-Ḥāsib (the arithmetician), is more appropriate. Little is known of his life. Ibn al-Nadīm tells us that he was an arithmetician and an astrologer (*al-munajjim*) as well as a man of excellence and learning. From Ibn al-Nadīm we also know the titles of five books by ˁUṭārid:

(1) *Kitāb al-Jafr al-hindī* (Book on Indian divination), which may have dealt with divination based upon letters of the alphabet or perhaps meteorological predictions;
(2) *Kitāb al-ˁAmal bi-'l-asṭurlāb* (Book on using the astrolabe);
(3) *Kitāb al-ˁAmal bi-dhāt al-ḥalaq* (Book on using the armillary sphere);
(4) *Kitāb Tarkīb al-aflāk* (Book on the arrangement of the heavens); and
(5) *Kitāb al-Marāyā al-muḥriqa* (Book on burning mirrors).

There is also a report that **ˁAbd al-Raḥman al-Ṣūfī** saw a book of ˁUṭārid (in latter's own handwriting) about the 48 constellations. In addition, both **Bīrūnī** and **Sijzī** attribute to ˁUṭārid a *Kitāb al-Miḥna al-munajjim* (Book on examining astrologers), a work specifically for testing the skills of astrologers. A text with a similar subject is by **Qabīṣī**. None of the above mentioned works attributed to ˁUṭārid are extant.

Of ˁUṭārid's works, only two have reached us. One is an astrological work entitled *Sirr al-asrār* (Secret of secrets) or *al-Asrār al-samāwiyya* (The secrets of the heavens), and also known as *Fuṣūl li-ˁUṭārid al-Ḥāsib fī al-asrār al-samāwiyya.* One can find excerpts in **Majrīṭī**'s *Ghāyat al-ḥakīm* that deal with the astrological topic of elections (*ihktiyārāt*). The other is *Kitāb al-Jawāhir wa-'l-aḥjār* (Book on the properties of stones), perhaps the earliest work of its kind in Arabic, which follows the so called Lapidary of **Aristotle**.

Giuseppe Bezza

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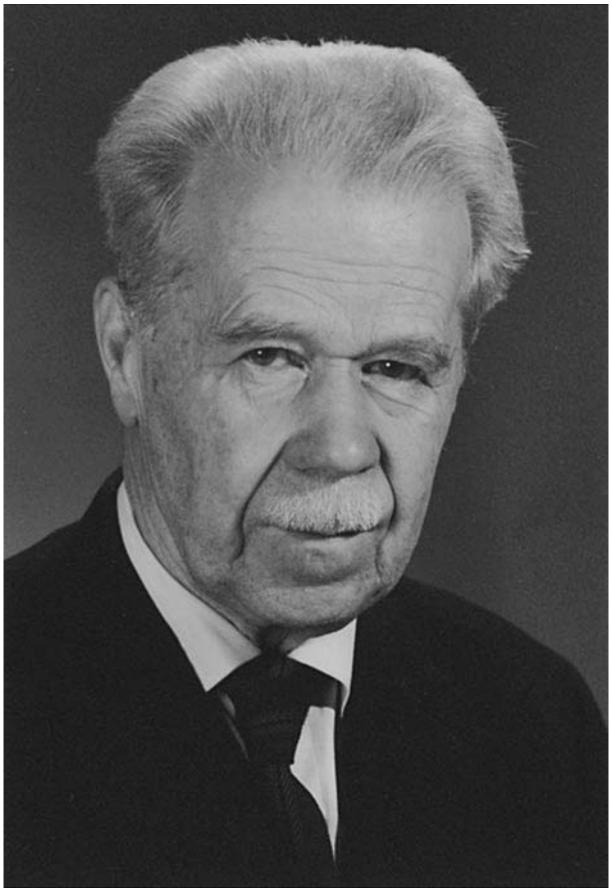
V

Väisälä, Yrjö

Born **Kontiolahti, Utra, (Finland), 6 September 1891**
Died **Rymättylä, Finland, 21 July 1971**



Yrjö Väisälä was influential in practical astronomy and the related fields of optics and geodesy. He developed several optical designs including a reflecting telescope with a spherical-aberration correction plate that he designed independently of **Bernhard Schmidt**. Väisälä discovered three comets and, with his students, over 800 asteroids. He was also a founding member of the amateur astronomers' association URSA, intended to promote astronomical education.

Väisälä's parents, Johannes and Emma Birgitta Veisell, had seven children, three of whom became well-known scientists. Yrjö's brother Kalle was a mathematician; another brother Vilho was a meteorologist and the founder of the Vaisala Company, which continues to manufacture scientific instruments.

Yrjö Väisälä obtained his Ph.D. in physics (optics) in Helsinki in 1922. After working briefly in the Geodetic Institute, he became the professor of physics at Turku University in 1922 and remained there for his entire career, serving as professor of astronomy from 1928 until his retirement in 1965.

Väisälä was the founder of the Turku University Observatory. Together with his students, Väisälä found six new comets, three of which bear his name, and over 800 asteroids. After his death, one of the asteroids was later identified by his student Liisi Oterma as a comet and is now known as comet 139/P Väisälä/Oterma. A record of 141 new asteroid discoveries was obtained in 1942 when the disturbing city lights had to be dimmed due to the war.

To facilitate his work Väisälä developed new methods. In his double-point method a photographic plate is exposed twice with an interval of approximately half an hour, while pointing the telescope in slightly different directions. On such a plate all stars appear as two dots close to each other while the dots produced by moving asteroids are more widely separated.

Before modern computers, the work of orbit calculation from observational data was very laborious. For this work Väisälä developed a new method, which was much faster to use than the earlier methods.

Väisälä also founded the Tuorla Research Center outside Turku. In Tuorla he built an optical laboratory, which has been developed further and is currently used for designing and making optics for telescopes and satellites. It is unfortunate that Väisälä published very little, and even many of his published results appeared in domestic series only. Väisälä's handwritten notes from 1924 indicate that he understood the principles of several modern telescope designs, Ritchey-Chrétien, Maksutov, and Schmidt camera, several years before they were "officially" invented. However, he thought these inventions were too simple for publishing. In an ordinary Schmidt camera, which is a telescope used for photographing large areas of the sky, the focal surface is not plane but curved. Väisälä built several Schmidt cameras of his own design with an additional lens to flatten the focal surface; such telescopes are sometimes called Schmidt–Väisälä telescopes. He also experimented with a multiple mirror telescope in which six spherical mirrors were grouped in a circle around a seventh mirror. Light was reflected to a common focus and spherical aberration corrected with a Schmidt-like corrector lens. In concept, the telescope was a precursor to the larger multiple mirror telescopes constructed several decades later.

Väisälä made several other inventions in the fields of physics, geodesy, and astronomy. His interferometer has been used to accurately measure lengths of baselines for geodetic surveys in several countries. He also found a method to make standard quartz meters of exactly the same length.

In 1913 Väisälä married Martta Johanna Levanto; they had four children: Marja, Aune, Veikko, and Vuokko. In 1951 he was elected to the Finnish Academy.

Hannu Karttunen

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Van Albada, Gale Bruno

Born **Amsterdam, the Netherlands, 28 March 1911**
Died **Amsterdam, the Netherlands, 18 December 1972**

Gale van Albada was well known for his work on the evolution of clusters of galaxies, the theory of formation of stellar associations and double stars, and for observations and orbit determinations of binary stellar systems.

Van Albada earned a Ph.D. in astrophysics at the University of Amsterdam as a student of **Herman Zanstra** and **Antonie Pannekoek** in 1945. His dissertation was a study of line intensities in stellar spectra. After a postdoctoral fellowship at the Warner and Swasey Observatories of Case Institute, Cleveland, Ohio, during which he worked on near-infrared spectra of late type stars with Jason John Nassau, van Albada was appointed director of the Bosscha Observatory at Lembang, Java, Netherlands East Indies. He arrived at the height of the revolutions that resulted in the independence of Indonesia in December 1949.

Van Albada revived the Bosscha Observatory during his 10 years there. Acquisition of a Schmidt telescope with an objective prism for the Bosscha Observatory permitted van Albada and his students to secure photometric and spectroscopic observations of many variable stars. Van Albada and his students also conducted an active program of photographic observations of double stars using the observatory's 23.6-in. refractor. From 1951 onwards, van Albada promoted astronomy very efficiently through his teaching at Bandung University. By the time he left the country, a new generation of astronomers was ready to take over astrophysical research in Indonesia.

In 1959, Leiden University welcomed van Albada home to the Netherlands for a short time until he was appointed director of research at the University of Amsterdam after the retirement of Zanstra. At the time of his death, van Albada was the director of the Astronomical Institute of the University of Amsterdam, where he also held a chair of professor of astronomy. Van Albada was married to Elsa van Dien, who was also well-known as an astronomer.

Léo Houziaux

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Van Allen, James Alfred

Born **Mount Pleasant, Iowa, USA, 7 September 1914**
Died **Iowa City, Iowa, USA, 9 August 2006**

American space scientist James Van Allen is sometimes called the father of space science, because he developed and provided instruments for the first US satellites that resulted in the discovery

of radiation zones encircling the Earth, subsequently named Van Allen belts.

Van Allen was the son of Alfred Morns and Alma Olney Van Allen, and was educated at Iowa Wesleyan College (BS in physics, in 1935, working with Thomas Poulter in physics and Delbert Wobbe in chemistry) and at the University of Iowa (MS: 1936; Ph.D. in physics: 1939). He married Abigail Fithian Halsey in 1945 and had five children.

After receiving his doctorate, Van Allen moved to the city of Washington, in September of 1939 under a Carnegie Fellowship, to work in the Department of Terrestrial Magnetism [DTM] of the Carnegie Institution of Washington, then directed by Merle Tuve. After the outbreak of World War II, the DTM became involved in fission research following the announcement of deuteron-induced fission of the uranium nucleus. Initially, Van Allen worked with the DTM Van de Graff accelerator studying the photodissociation of the deuteron. Soon, however, he became involved in the prewar effort to improve the technical capabilities of the United States navy, specifically through the development of a "proximity fuse" that would explode upon approaching a target. By the spring of 1942, the fuse work was transferred to the Applied Physics Laboratory [APL], which was established under the auspices of Johns Hopkins University to develop the concept and introduce it to the navy. By November 1942, Van Allen was commissioned as a lieutenant in the United States Naval Reserve and sailed to the Pacific with a supply of proximity fuses for use by the navy's antiaircraft guns.

As it turned out, building rugged electronics to be shot out of a gun with enormous force was excellent preparation for a number of subsequent postwar tasks undertaken by Van Allen and his team. At the end of the war, they performed high-altitude experiments with captured German V-2 rockets to measure cosmic radiation and solar ultraviolet spectra and to take pictures of Earth's curved horizon, among other things.

At the end of 1950, Van Allen moved to Iowa to become professor and head of the Department of Physics at the university where he had obtained his Ph.D. There, he continued his high-altitude research, but now with the domestic Aerobee rocket that he helped develop while at APL. This set the foundations for involvement in the forthcoming entry of the United States into the space era. The V-2 Rocket Panel, set up after the war to oversee high-altitude research, evolved into the Upper Atmosphere Rocket Research Panel and later into the Rocket and Satellite Research Panel with Van Allen as a principal driver and eventually as chair. This panel organized US participation in the 1957/1958 International Geophysical Year [IGY], and panel members actively promoted the use of scientific satellites around Earth as part of the IGY and spearheaded the science base of the National Aeronautics and Space Administration [NASA], which also was established in 1958.

The implications of a brief stay at Princeton University during this period are mentioned in the article on **Martin Schwarzschild**.

By 1956, Van Allen had already submitted a formal proposal to the IGY for an instrument to be included in the payload of an Earth satellite. The objective would be to map the global distribution of cosmic rays, a goal that he and his collaborators had been pursuing with balloons and rockets for more than a decade. The proposed instrument was included in the payload of the first flight of the Army's Jupiter C rocket, launched on 31 January 1958. This first US satellite, named Explorer I, worked well, and the Iowa Geiger–Mueller tube's high counting rates turned out not to be at all consistent with the modest intensities expected from high-altitude cosmic rays. These measurements were later combined with those of Explorer III, which carried a tape recorder and was capable of providing global coverage. The two data sets resulted in the discovery of the radiation belts that bear Van Allen's name, huge regions of space populated mostly by protons and electrons trapped in the Earth's magnetic field with energies extending to millions of electron volts for the electrons and hundreds of millions for the protons (*i. e.*, sufficient energies to penetrate several inches of steel). The public announcement was made at the National Academy of Sciences on 1 May 1958. Significantly, confirmation of this key discovery by Van Allen and colleagues was provided later that month by the launch of Sputnik III. The Iowa instrument "factory" continued to provide radiation detectors for subsequent satellites (Explorer IV and Pioneers I and III, all in 1958) that provided a large body of data establishing the radial dimensions of the region containing trapped radiation, subsequently named the "magnetosphere."

By late 1958, NASA had taken over most space research in the United States. Under NASA support, Iowa instruments and entire satellites were built and flown, with some data reception through makeshift antennas near Iowa City. Seminal discoveries were made that illuminated plasma processes in every region of Earth's magnetosphere.

In the meantime there was incessant curiosity about potential magnetospheres around other planets and the properties of the interplanetary medium in between. The National Academy of Sciences had now established the Space Science Board, chaired by Lloyd Berkner, with Van Allen as an influential member. Soon, plans were made for missions to Venus and Mars, and Van Allen's radiation detectors were included in both payloads.

Mariner II passed by Venus on 14 December 1962 but did not detect any radiation, suggesting the absence of an extended, Earth-like, magnetosphere. The plasma detector on Mariner II, however, did establish firmly the presence of the solar wind, a continuous stream of plasma flowing radially outward from the Sun, and delineated its properties for the first time. Similarly, Mariner IV passed by Mars on 15 July 1965 and established an upper limit to the Martian magnetic moment as 0.001 of the Earth. Nevertheless, the Mariner IV mission made several discoveries en route, including electron emissions in solar flares and an 8-month record of solar x-ray flare activity.

This "null" result in finding magnetospheres at Earth's neighbors only accelerated the search for such regions in the outer planets, the prime candidate being Jupiter, a known radio emitter since the 1950s. Van Allen's Lunar and Planetary Missions Board soon recommended that NASA proceed with two spacecraft to investigate the region around Jupiter. Pioneers 10 and 11 (launched in 1972 and 1973, respectively) carried a set of Iowa's Geiger–Müller radiation detectors along with other instruments. They encountered Jupiter in 1973 and 1974 and established the presence of a huge magnetosphere with high-energy/high-intensity radiation belts and a magnetic field easily 10 times that of Earth. The Pioneer 11 trajectory was deflected using Jupiter's gravity to direct the spacecraft toward an encounter with Saturn in 1979, where it measured the latter planet's magnetic field and magnetosphere.

Even before the two Pioneers were launched, the Van Allen Board had recommended that NASA take advantage of a rare alignment of the outer planets to plan and launch what eventually became the Voyager 1 and 2 missions. These spacecraft were to perform comprehensive investigations not only of Jupiter and Saturn, but also Uranus and Neptune. The Voyager missions became a spectacular success and "rewrote the book" on humanity's knowledge of the outer planets.

Van Allen's fascination with Jupiter did not stop with the Voyager missions. He chaired a working group in the mid-1970s that recommended a mission to orbit Jupiter and drop a probe into its atmosphere. This mission resulted in the Galileo spacecraft, launched in 1989 and orbiting Jupiter in 1995.

In addition to his purely scientific contributions, Van Allen was a strong exponent of the view that most space research can be accomplished by robotic spacecraft and automated equipment, while human crews are of limited utility and are only needed for laboratory-type experiments in low gravity conditions. In this vein, he was an ardent opponent of manned spaceflight, particularly the space shuttle and space station, from the inception of each program.

In addition to his research work, Van Allen was an educator at both the undergraduate and graduate level, a leader in science policy-making at the national level, and an eloquent spokesman on scientific issues at various public fora.

Van Allen's legacy includes the supervision of 34 Ph.D. dissertations and 45 MS theses, some 260 published papers between 1967 and 2002, and a number of books and public and technical lectures throughout the world. He was the recipient of 15 honorary degrees, the United States National Medal of Science (1987), the Crafoord Prize of the Royal Swedish Academy of Science (1989), and a number of other honors and awards.

Stamatios Kimigis

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Van Biesbroeck, Georges-Achille

Born **Ghent, Belgium, 21 January 1880**
Died **Tucson, Arizona, USA, 23 February 1974**

Georges Van Biesbroeck, the leading observer of close double stars in America during his lifetime, was renowned for his long hours at the telescope spanning nearly 70 years. He retired as a University of Chicago faculty member at age 65, only to begin a second career in astronomy that ended with his death.

Though his father was an artist, Van Biesbroeck himself studied civil engineering at the University of Ghent. Indeed, he was employed for 6 years (1902–1908) by the Brussels Department of Roads and Bridges. Even so, Van Biesbroeck was fascinated by astronomy from an early age; he studied the subject in college. He volunteered as an observer at the Royal Observatory (Uccle, near Brussels) and spent time at the Royal Observatory (Greenwich) and various observatories in Germany (including Heidelberg, working with **Maximilian Wolf**, and Potsdam, working with **Johannes Hartmann** and **Karl Müller**), before returning to Uccle as an adjunct astronomer in 1908. It was from Belgium that he observed an annular eclipse in 1912, presumably kindling his later interest in eclipses, which he observed whenever possible.

In June 1914 Van Biesbroeck, still an adjunct astronomer at Uccle, was contacted by **Edwin Frost**, director of the Yerkes Observatory. Frost sought an expression of interest from Van Biesbroeck regarding a potential opening for an astronomer with micrometer experience and an interest in double-star work. Faced with the certain need to replace **Sherwin Burnham** when he retired, Frost was also concerned about the eventual retirement of **Edward Barnard**, already ill with late-onset diabetes. Van Biesbroeck accepted Frost's offer and came to Yerkes as a visiting professor to work with the 40-in. refractor on a temporary assignment. He arrived in Williams Bay, Wisconsin, USA in late August 1915. Van Biesbroeck spent 10 months at Yerkes during which he performed a variety of tasks to Frost's satisfaction and appeared to fit in well with the Yerkes staff, but then returned to his family in war-torn Belgium. When Frost offered him a permanent assignment, in spite of the continuing dangers during World War I, Van Biesbroeck took his family on a harrowing emigration through neutral The Netherlands and traveled to the United States by way of Norway, arriving in Williams Bay in 1917.

In addition to his double star observing at Yerkes, Van Biesbroeck routinely measured the positions of comets and asteroids and made observations of variable stars depending on the instruments available for his use. He was also, in effect, the resident engineer at Yerkes and participated in the design and construction of many new instruments. When the University of Chicago and the University of Texas agreed to jointly develop and operate the McDonald Observatory near Fort Davis, Texas, in the 1930s, Van Biesbroeck tested and approved many of the optical systems. He also designed and constructed a complete mounting for a 20-in. Schmidt telescope for which the optics were never completed.

Though he became professor emeritus at the University of Chicago in 1945, Van Biesbroeck's observations at the Yerkes and MacDonald observatories continued without interruption. At an age when many men stay close to home, in 1947, 1948, and 1952 he traveled to Brazil, Korea, and Sudan, respectively, to explore the relativistic deflection of starlight during eclipses of the Sun. In between these years (1949/1950), Van Biesbroeck undertook a 6-month mission for the Belgian government to conduct an observatory site survey in the remote Congo.

In 1963, the Yerkes Observatory director advised Van Biesbroeck that, in consideration of his age and the perceived dangers that using the telescope entailed, he could no longer use the 40-in. refractor. Incensed at this denial of his continued capability, Van Biesbroeck accepted an offer from **Gerard Kuiper** to join the staff of the University of Arizona's Lunar and Planetary Laboratory, where he remained active as an astronomer until the end of his life. He traveled to Perry, Florida, at the age of 90 to observe the solar eclipse of 7 March 1970 but was clouded out. It was his last attempt to observe an eclipse.

All told, Van Biesbroeck amassed a body of approximately 600 publications. These covered his observations and computed orbits for double stars, asteroids, comets, and planetary satellites. His orbit of Nereid resulted in the determination of a more accurate mass for Neptune. He was the discoverer of 11 asteroids and three comets (C/1925 W1, C/1935 Q1, and 53P/1954 R1). Van Biesbroeck was credited with the discovery (in 1944) of the least luminous star recognized at the time: a companion of BD +04° 4048 (Van Biesbroeck's star).

Like so many of his contemporaries, Van Biesbroeck's life in astronomy was a quest for ever-increasing aperture. He started out as an observer of close binary stars with a 15-in. refractor at Uccle. At Yerkes he made use of the 40-in. refractor, or the 24-in. reflector if the former was unavailable, continuing in the tradition of Burnham and Barnard. In fact, it was Van Biesbroeck and Barnard's niece Mary Calvert who edited Barnard's unpublished work after his death. At MacDonald, Van Biesbroeck used the 82-in. reflector which he helped design. He continued to receive observing time on large (for the time) telescopes into his 10th decade. In all, Van Biesbroeck made thousands of double star measurements including those of stars he had discovered.

In his lifetime Van Biesbroeck was awarded the Gold Medal of the Royal Danish Society of Sciences, the Valz Prize of the Paris Academy of Science, the Donohoe Comet Medal of the Astronomical Society of the Pacific (twice), the Franklin L. Burr prize of the National Geographic Society, honorary membership in the Royal Astronomical Society of Canada (one of only 15), and an honorary doctorate from the University of Brussels (1935). He was a fellow of the Royal Astronomical Society. Minor planet (1781) was named for Van Biesbroeck by the International Astronomical Union.

Van Biesbroeck's wife Julia died before him. He was survived by two daughters and a son.

Thomas Hockey and *Thomas R. Williams*

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Van de Kamp, Peter [Piet]

Born **Kampen, the Netherlands, 26 December 1901**
Died **Amsterdam, the Netherlands, 18 May 1995**

Dutch–American astrometrist Peter van de Kamp is remembered for an extended series of searches for low-mass companions to nearby stars, which greatly increased our knowledge of binary systems, but found none of the extrasolar-system planets he had hoped for. He was the son of Lubbertag and Egelina (*nee* Van der Wal) van de Kamp. At an early stage Piet, or Peter as he became known in the United States, was exposed to music through his father who played the organ in a local church and had a piano at home. In fact, when Peter enrolled at the University of Utrecht, the Netherlands, working with A. A. Nijland, in 1918, he had to choose between music and astronomy. He decided the latter would lead to a better career. Van de Kamp graduated from the University of Utrecht in 1920 and received a doctorate in 1922. After working as an assistant at the Kapteyn Astronomical Laboratory, Groningen, from 1922 to 1923, he came to the United States, becoming a naturalized citizen in 1942.

In the 1920s and 1930s, Samuel A. Mitchell brought together a group of astronomers of varied interests at the University of Virginia, Charlottesville. Besides van de Kamp, who arrived in 1923, there were A. N. Vyssotsky, a specialist in stellar motions; Emma T. R. Williams, with interests in the same field, who would marry Vyssotsky; **Harold Alden**, interested in stellar parallaxes and a future director of Virginia's Leander McCormick Observatory; **Rupert Wildt**, an astrophysicist who would move to Yale; plus M. Kovalenko and D. Reuyl. Many of these people formed the nucleus of the Observatory Mountain Orchestra with van de Kamp as conductor. From such a beginning the Charlottesville Symphony Orchestra grew.

Van de Kamp served as an associate astronomer at the University of Virginia's Leander McCormick Observatory, from 1923 to 1924; then he accepted a Martin Kellogg Fellowship at the Lick Observatory, from l924 to 1925, while he completed his Ph.D. at the University of California at Berkeley. He was awarded a similar degree, from Groningen University, the following year, for a thesis on systematic errors in the proper motions of stars in the Boss catalog, carried out under **Pieter van Rhijn**. Van de Kamp appears to have been the first Dutch astronomer to earn a Ph.D. in the United States.

Van de Kamp returned to Virginia as an instructor in 1925 and was promoted to assistant professor in 1928. He held this post until in 1937 he was invited to Swarthmore College, Swarthmore, Pennsylvania, as an associate professor and director of the Sproul Observatory. He was promoted to professor in 1940, a rank Van de Kamp held until his retirement in 1972 when he was appointed research professor.

Van de Kamp was an able and popular teacher. He occupied a number of visiting professorships at Harvard University (1936), at Wesleyan University (1956), and at the New School for Social Research (1944–1962). In addition he was a Fulbright Professor at the University of Paris (1949), and at Amsterdam University (1972). Van de Kamp was awarded the President and Visitor's Prize of the University of Virginia for 3 years (1927, 1937, and l938). In addition he won a Glover Award from Dickinson College (1961), Swarthmore's Nason Award (1963), and the Gold Medal of Philadelphia's Rittenhouse Society (1965).

An early concern of van de Kamp was the effect of interstellar absorption on distances in various directions within the Galaxy. Such absorption causes a star or other object like a globular cluster to appear fainter than it actually is and thus at a greater distance. In applying his results to an estimate of the distance to the galactic center, van de Kamp lowered **Harlow Shapley**'s original estimate by some 4,000 parsecs (about 13,000 light years) to 12,000 parsecs.

During his tenure at Swarthmore, van de Kamp became recognized internationally for his research in astrometry with long-focus telescopes such as the 60-cm refractor of Sproul Observatory. Here he expanded his research program to include a study of nearby stars. One of the goals of this project was to discover low-mass companions and, potentially, to find out if other stars were accompanied by planets. At that time, a half century ago, the question of the existence of other planetary systems was not the popular question that it is today, nor was the technology to pursue this question as refined as it is now. Experience had shown that "unseen" companions of visible stars could be detected from their mutual gravitational attraction, which would cause a wobble in the visible object's track across the plane of the sky; its proper motion, the change in its angular position over a period of time, would not be a straight line. Companions to Sirius and Procyon had been detected in this manner by **Friedrich Bessel**.

In 1917 the American astronomer **Edward Barnard** found that a faint, nearby red star in Ophiuchus had a very large proper motion – in fact the largest ever measured. This object was from that time on called Barnard's Star. From the analysis of data accumulated from 1916 through 1962 at the Sproul Observatory, van de Kamp, in 1963, announced that observed deviations of this star's motion could be attributed to a planet moving about it in a period of 24 years. His final analysis (1982) indicated that Barnard's star had planets with masses 0.7 and 0.5 times that of Jupiter in orbits with periods of 12 and 20 years, respectively. However, by then, other experts had become skeptical, blaming the results on instrumental effects. Most recently a study of images of Barnard's star compiled at the Leander McCormick Observatory from 1969 to 1998 showed no sign of planets.

The research program that van de Kamp initiated has led to the discovery of a number of low-mass stellar companions and has increased our knowledge of stellar duplicity in the Galaxy. From his studies of known binary stars, he contributed additional data on stellar masses, one of the basic parameters of the physical Universe.

In 1954 van de Kamp took a leave of absence from Swarthmore for the academic year to become the first program director for astronomy in the National Science Foundation, a position he held through the summer of 1955. One of his innovations was to solicit research proposals from all members of the American Astronomical Society. He also became involved with a panel, chaired by **Robert McMath**, that would lead to the eventual creation of the Association of Universities for Research in Astronomy [AURA], Incorporated, and the Kitt Peak National Observatory. Subsequently van de Kamp became a director-at-large of the AURA board. For his research on binary stars, van de Kamp was named president of Commission on Double Stars of the International Astronomical Union, 1958–1964. He also became a member of the United States National Committee.

Van de Kamp was a member of several other organizations including the American Astronomical Society, the Astronomical Society of the Pacific, Sigma Xi, Phi Beta Kappa, and the Royal Dutch Academy. He married Olga Ptrushoka in 1947. Toward the end of World War II he became a member of the Alsos Mission, a group charged by the Office of Scientific Research and Development with studying the progress of science and technology – notably atomic bombs, radar, and guided missiles – in Germany under the Nazis.

Throughout his life van de Kamp felt that astronomy was a marvelous synthesis of art and science. He played the viola, violin, and piano. In addition to the amateur orchestra that he had directed at the University of Virginia he became the conductor of the Swarthmore College Orchestra. He loved to play ragtime music and was fond of the blues. Among his own compositions was *Blackout Blues*, to commemorate the great northeastern blackout of November 1965.

An oral-history interview with van de Kamp may be found at the Niels Bohr Library of the American Institute of Physics in College Park, Maryland. His research correspondence along with other papers have been deposited at the Library of the United States Naval Observatory in Washington.

George S. Mumford

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Van de Sande Bakhuyzen [Bakhuysen], Hendrik Gerard [Hendrikus Gerardus]

Born **The Hague, the Netherlands, 2 April 1838**
Died **Leiden, the Netherlands, 8 January 1923**

Dutch astronomer Hendrikus van de Sande Bakhuyzen, primarily known for precise measurements of positions of stars, was the son of a successful landscape painter, also named Hendricus. After attending the local gymnasium (a classical secondary school), Bakhuyzen began his studies in 1855 at the Delft Polytechnic, where in 1859 he took a degree in civil engineering. He subsequently matriculated at the University of Leiden, where he came under the powerful influence of the astronomer **Frederik Kaiser**. In 1863 Bakhuyzen obtained his doctorate with a dissertation on the flexure of the recently acquired meridian circle at the Leiden Observatory.

For a year Bakhuyzen worked at the new, but poorly staffed, Leiden Observatory as an unpaid observer. When his prospects did not improve, he decided to accept a post as teacher, first at the gymnasium in The Hague, then, 2 years later, at the newly instituted Hogere Burgerschool (technical secondary school) in Utrecht. In 1867 he was appointed professor of applied physics at Delft University. Two years later he married Geertruida van Vollenhoven of Rotterdam. They had a son and two daughters. When Kaiser died in 1872, Bakhuyzen succeeded him at the University of Leiden as professor of astronomy and director of the observatory. He held this position until his retirement in 1908. During this entire period he was assisted by his brother Ernst Frederik (1848–1918), who held the position of first observer. Ernst would eventually succeed Hendrick as director of the observatory.

Bakhuyzen continued the tradition established by Kaiser: the exact determination of stellar positions. The principal instrument in the observatory was the Pistor and Martins meridian circle, and up to 1919 meridian astronomy remained the main domain of activity at the observatory. The program included observations of 84 circumpolar stars and, subsequently, of 303 southern stars, all selected by the Astronomische Gesellschaft as reference stars. These measurements were intended as a contribution to **Arthur von Auwers**' Fundamental Catalog for the zones of the Astronomische Gesellschaft. Unfortunately, Bakhuyzen's high demands on the reduction of the data, and the small number of (human) computers at the observatory, delayed the publication of the observations, thereby preventing their inclusion in the Catalog.

All of Bakhuyzen's research testifies to his penchant for precision. In the spirit of his predecessor he meticulously investigated all possible instrumental and personal errors. In 1879, he was the first to provide solid evidence for the influence of the magnitude of stars on the personal equation. To such ends he had designed an apparatus to determine the personal equation by the observation of moving artificial stars. To improve precision in the observation of stellar occultations by the Moon, he also investigated the effect of the brightness of a point on the time of perception of its sudden appearance and disappearance (a somewhat different phenomenon). (The personal equation describes the systematic differences in the positions of the same stars determined by different observers using the same equipment, it arises from systematic differences in estimating the time at which a star crosses a hair-like mark in the field of the telescope.)

Atmospheric refraction was a favorite subject of the Bakhuyzen brothers. Between 1879 and 1898 the Leiden Observatory determined the zenith distances of two zones of stars, one near the zenith of the Cape of Good Hope, the other near the zenith of Leiden. These stars were also observed at the Cape, and comparison of the conclusions resulted in a correction to the adopted value of the constant of refraction. In 1907 Bakhuyzen published his research on the temperature distribution in the atmosphere, based on measurements made during balloon ascents, and the resulting effect on atmospheric refraction.

Other investigations that testify to his predilection for precision include Bakhuyzen's redetermination in 1885 of the rotation period of the planet Mars. Using all previous observations, including those by **Christiaan Huygens**, **Johann Schröter**, and Kaiser, Bakhuyzen derived the rotation period with a probable error of about one part per million.

Much of Bakhuyzen's research concerned geodetical questions. He served as president of the Dutch National Geodetic Committee from 1882 onwards, and as *secrétaire perpétuel* of the International Geodetic Association from 1900. In the former capacity he supervised the precision leveling, as well as the triangulation, of the Netherlands. The committee also conducted tidal research in Dutch ports. In this connection Bakhuyzen investigated the change of sea level at Amsterdam and Den Helder from 1700 to 1910. He used the results to discuss the variation of latitude as well as the secular motion of the soil. Bakhuyzen's "compensation" of all European determinations of longitude, published in 1894, became the main source for the longitudes of European observatories as given in the national ephemerides.

Bakhuyzen participated in several national and international committees. From 1888 to 1910 he served as president of the Royal Dutch Academy of Sciences. He represented the academy at the triennial meetings of the International Association of Academies from 1904 to 1913. Bakhuyzen was a member of the (German) Astronomische Gesellschaft, serving as its vice president from 1889 to 1896. He was a correspondent of the Institut de France and a foreign member of the Royal Astronomical Society, the Italian Academia dei Lincei, and the Royal Belgian Academy. Bakhuyzen also took a prominent share in the international conferences of the *Carte du Ciel* Project.

Frans van Lunteren

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Van den Bos, Willem Hendrik

Born **Rotterdam, the Netherlands, 25 September 1896**
Died **Johannesburg, South Africa, 30 March 1974**

During his career of over 30 years in South Africa, Willem van den Bos discovered approximately 3,000 new visual double stars and likewise computed the orbits of almost 100 double stars, carrying the work well into his retirement until forced to stop by declining health.

Van den Bos entered the University of Leiden in 1913, but his studies were interrupted by war. He rose to the rank of lieutenant in the Netherlands Coast Artillery. Afterwards, Van den Bos resumed his studies at a time when such illustrious personalities as **Albert Einstein**, Paul Ehrenfest, **Hendrik Lorentz**, **Willem de Sitter**, and **Ejnar Hertzsprung** were faculty members. In 1921, he became a member of the Leiden Observatory staff. His 1925 doctoral dissertation was on the subject of binary stars. **Robert Innes**, director of the Union (later Republic) Observatory, Johannesburg, South Africa, offered Van den Bos a short-term research position to utilize the 26.5-in. refractor, construction of which was to be completed in 1927. After 3 years, Van den Bos was appointed chief assistant by Innes's successor, H. E. Wood, and eventually succeeded him as director in 1941, retaining this position until his retirement in 1956.

Van den Bos compiled a card catalog of southern double stars that was embodied in one volume of the *Lick Observatory Publications* Series. This comprehensive account presented measurements of more than 64,000 binary stars. Van den Bos himself supplied that portion of the catalog listing binaries south of declination −19°. He later updated the catalog when appointed a visiting astronomer at the Lick Observatory, Mount Hamilton, California. His paper on binary-star orbit computation in the University of Chicago's *Stars and Stellar Systems* (1962) series became a classic reference work.

As an aid to observational astronomers and orbit computers, Van den Bos discussed, in 1958, techniques for obtaining good double-star measurements and listed sound etiquette for reporting such observations. He also discussed the relative merits of refractors versus reflectors for double-star observations. For the presentation of results from orbital calculations, Van den Bos advocated the system laid down by the International Astronomical Union [IAU] in 1935.

In connection with the formation of the South African Astronomical Observatory [SAAO] in the early 1970s, Van den Bos and **William Finsen** expressed considerable reservations toward the plan to relocate the principal observing facilities to Sutherland and to establish the SAAO's headquarters at Cape Town. Loss of the dedicated Union/Republic Observatory refractor was a serious blow to fundamental double star research, in the Southern Hemisphere.

Van den Bos was elected president of IAU Commission 26 (Double Stars) from 1938 to 1952, the longest serving president of this commission. He was the recipient of the Gold Medal of the Royal Danish Academy, and the Gill Medal of the Astronomical Society of Southern Africa.

John McFarland

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Van den Hove, Maarten

Born **Delft, The Netherlands, 1605**
Died **Leiden, The Netherlands, 17 August 1639**

Martinus Hortensius' significant contributions were related to the dissemination of the Copernican theory and finding the angular diameter of the Sun. He corresponded with **René Descartes**, **Marin Mersenne**, **Pierre Gassendi**, **Christiaan Huygens**, **Nicolas de Peiresc**, **and Wilhelm Schickard**.

Hortensius was named Maarten van den Hove after his mother's father; his father's family name was van Swaanswijk. He was Isaac Beeckman's student at Dordrecht and attended the Latin School of Rotterdam from December 1621 to 1627, after which he left the Dordrecht area. Hortensius then became **Willebrord Snel**'s pupil, but was not enrolled at the university. He later enrolled at Leiden and Ghent to study mathematics and theology from 1628 to 1630.

Hortensius was a self-taught astronomer who at first followed the lead of **Tycho Brahe**. He made several observations of the Sun with Beeckman in Dordrecht. Beeckman introduced him to **Philip Lansbergen** in Middelburg. Hortensius later translated Lansbergen's *Commentations in motum terrae* (1630). In the preface, Hortensius mentioned that Lansbergen had told him of several mistakes made by Brahe; he also discussed **Johannes Kepler**'s views regarding the distance of the Sun. This work of Lansbergen was challenged by Libert Froidmond in Louvain and **Jean Morin** in Paris, while defended by his son **Jacob Lansbergen**. The preface in particular provoked a response from Kepler concerning the measurement of the diameter of the Sun, *Ephemeris ad annum 1624.* Although Kepler had died, Hortensius, on the advice of Lansbergen, gave a public response to Kepler in *Responsio ad additiunculam D. J. Kepleri praefixam Ephemeridi ejus in annum 1625* (1631) and dedicated it to Abraham van der Meer, Councillor in the States-General of Holland.

Hortensius then wrote *Dissertatio de Mercurio in sole viso et venere invisa, instituta cum clarissimo ac doctissimo Viro D. Petro Gassendo* (1633). About this time he was also actively involved with improving the telescope. In March 1634 Hortensius was asked to lecture in mathematics at the newly established Amsterdam Atheneum. In May 1634 he accepted the position with a speech, *De dignitate et utilitale matheseos.* Hortensius later taught a course on the beginnings of astronomy. It was during this time that he translated Willem Blaeu's *Guilielmi Blaeu Institutio astronomica de usu globorum et sphaerorum coelestium ac terrestrium* (1634).

Hortensius was appointed full professor in the Copernican theory in July 1635. He lectured on optics and dedicated these lectures, *De oculo ejusque praestantia* (1635), to the Polish nobleman Hyacinthus de Rozdrazew Rozdrazewsky. Soon afterward Hortensius taught courses in navigation. Throughout this period he traveled several times to Leiden, Delft, and The Hague. In November 1636, he was nominated to a commission that was formed to discuss with **Galileo Galilei** his system of longitudinal determination by observing Jupiter's satellites. On 20 August 1637 1,000 guilders was paid to acquire the necessary instruments to conduct this research. Several letters were exchanged by Hortensius with Hugo de Groot and Elia Diodati as well as with Galilei, who on 5 September 1637, provided information regarding the telescope, the astronomical almanac, and the ephemerides.

In 1639 the University of Leiden appointed Hortensius full professor. He became ill soon after his appointment and died, leaving behind him a son. He was buried at Delft.

Unpublished letters of Hortensius and Peiresc are in the library of Inguimbert in Carpentras and also in the Bibliothèque nationale in Paris. His correspondence with Schickard is in the Stuttgart Library, and that with Constantine Huygens is in the Royal Academy of Amsterdam.

Suhasini Kumar

Alternate name

Martinus Hortensius [Ortensius]

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Van Lansbergen, Philip

➜ **Lansbergen, Philip**

Van Maanen, Adriaan

Born **Sneek, Friesland, The Netherlands, 31 March 1884**
Died **Pasadena, California, USA, 26 January 1946**

Dutch–American observational astronomer Adriaan van Maanen is, sadly, remembered almost entirely for a mistake, measurements that he thought indicated that material was flowing out along the arms of the spiral nebulae, or that the nebulae were rotating, at speeds such that they could not possibly be located outside of the Milky Way Galaxy. This prolonged the debate around 1920 about whether other galaxies even existed.

Van Maanen received his degrees from the University of Utrecht: B.A. (1906), M.A. (1909), and Ph.D. (1911), the last with a thesis on "The Proper Motions of 1418 Stars in and near the Clusters h and Chi Persei," written in Dutch but with a translation in English financed by a wealthy relative. Although **Albert Nijland**, professor of astronomy at Utrecht, was his official advisor, most of van Maanen's work was actually done at the University of Groningen (1908–1910) under the influence of **Jacobus Kapteyn**.

It was Kapteyn who arranged for van Maanen to spend a year, 1910/1911, at Yerkes Observatory as a volunteer astronomer, financed by that same wealthy relative, Mr. K. Blokhuis, the owner of the Gasworks at Haarlem, the Netherlands. **George Hale** then appointed van Maanen to a staff position at Mount Wilson Observatory, preferring him to either **Ejnar Hertzsprung** or **Pieter van Rhijn** as successor to **Philip Fath** (discoverer of emission lines in the cores of a few spiral galaxies now called Seyfert galaxies). Van Maanen thus became the first of a large number of Dutch astronomers to pursue careers in the United States, frequently organized by Kapteyn, and later by van Rhijn and **Willem de Sitter**. Others who appear in this book include **Willem Luyten**, **Peter van de Kamp**, **Dirk Brouwer**, **Bart Bok**, **Gerard Kuiper**, and **Adriaan Wesselink**.

At Yerkes, van Maanen continued his work on stellar parallaxes and proper motions, studying stars in and around the Orion Nebula. When he first arrived at Mount Wilson, there was no apparatus appropriate for such work there, so he participated in the program on stellar and solar spectroscopy. Van Maanen concluded that the average magnetic field of the Sun was quite large. He did this on the basis of measurements of Zeeman broadening of spectral features that must have been subject to some systematic error comparable with his later one in spiral nebulae. This is because the actual average field is, at most, 10% of what van Maanen deduced.

In 1914, the Cassegrain focus at the 60-in. telescope became available, and van Maanen resumed astrometric work, which had traditionally been done only with very long-focal-length refracting telescopes. He undoubtedly established that astrometry with reflectors was possible, measuring his 500th parallax in 1945. Van Maanen also concluded that the number of stars near the Sun as a function of real brightness peaks near absolute magnitude 10.3, only a factor 100 fainter than the Sun. There is indeed such a peak, but a factor of 10 fainter than this.

In 1917, van Maanen reported a star with a parallax of 0.24 arc sec (*i. e.*, only a little more than 4 parsecs away), with apparent magnitude 12 and the color of a G star like the Sun. With a bit of arithmetic, one can see that this means a brightness of 0.02% that of the Sun and, with the same color (temperature), that the star must have a radius only about 1% that of the Sun, about the same as that of the Earth. Now called van Maanen's star, this was the second white dwarf discovered (following Sirius B by **Walter Adams**), and it remains unique in having strong features due to iron in its spectrum, and little or no hydrogen. (Helium would be invisible at its temperature near 6000 K.)

Between 1916 and 1923, van Maanen sought to measure proper motions in several spiral nebulae, using plates taken both before and during his tenure with several different cameras and telescopes. He devised, and had constructed for the purpose, a stereocomparator, which allowed the observer to look at one plate with each eye, so that anything that had moved would seem to jump out of the image. The motions van Maanen reported, about 0.02 arcsec/year, would have corresponded to physical speeds of at least 10,000 km/s for any location that would permit the spirals to be separate galaxies comparable in size with the Milky Way. This would have implied enormous masses. **Harlow Shapley**, then a colleague and close friend, automatically believed the results, and his opposition to the existence of external galaxies, voiced at the debate with **Heber Curtis**, was based partly on van Maanen's work.

In 1923, when the discovery of Cepheid variables in a couple of spirals had been made by **Edwin Hubble** (but before this was widely announced), **Knut Lundmark** remeasured the plates and found no evidence for proper motions. Van Maanen never entirely recanted. Hubble repeated the measurements again in 1935 with the same plates and comparator and found no motion, while van Maanen's own remeasurements merely halved his previous result. The comparator itself was used successfully by others, though it retained a sign instructing astronomers to consult van Maanen before touching it, long after his death. Computer reprocessing of the numbers he recorded found no error in the arithmetic. Thus no one has ever fully understood what went wrong, but it was to do with how van Maanen perceived the images on the plates. It is perhaps significant that, during that period and long after, he was the only one at Mount Wilson working primarily in astrometry. The others were spectroscopists and interpreters of images. In any case, his reputation never fully recovered.

Van Maanen maintained memberships in the International Astronomical Union, in astronomical societies in England, France, Germany, and the United States, and in at least five Dutch scientific organizations, but seems never to have been elected to office or to have received any special recognition from them. He never married, but was a social person, active in the Valley Hunt Club, Young Mens' Christian Association, and the local chamber music society (as an organizer, not a performer).

Adriaan Blaauw

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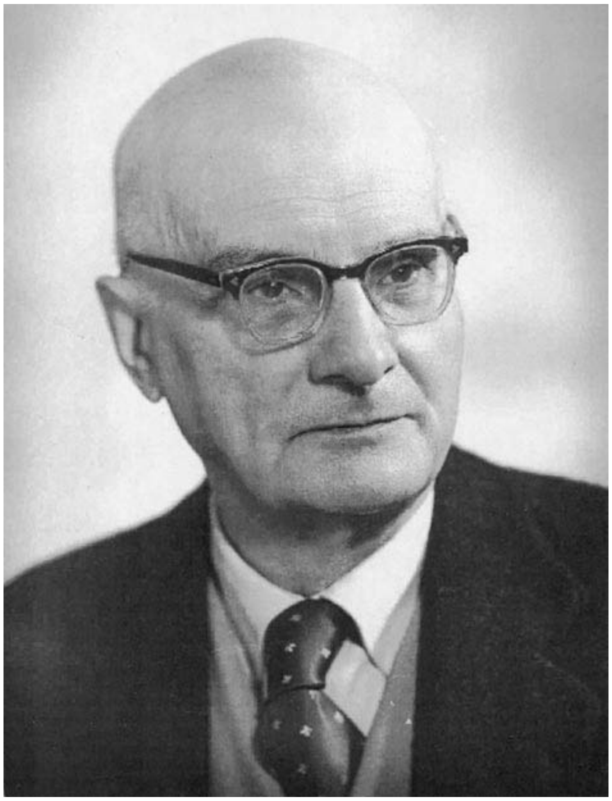
Van Rhijn, Pieter Johannes

Born **Gouda, The Netherlands, 24 March 1886**
Died **Groningen, The Netherlands, 9 May 1960**

Dutch statistical astronomer Pieter van Rhijn made an important determination, called the van Rhijn luminosity function, of the numbers of stars in the solar neighborhood as a function of their absolute brightness. He was the son of Cornelis H. van Rhijn, a professor of theology at Groningen University, and Aletta J.F. Kruijt. Van Rhijn and his wife, *née* Regnera L. G. C. de Bie, had one son and one daughter.

Van Rhijn received his Ph.D. from the University of Groningen in 1915 for work carried out under the direction of **Jacobus Kapteyn** and partly done at the Mount Wilson Observatory



between 1912 and 1914. He was appointed professor of astronomy at Groningen in 1921.

A collaborator, and successor of J. C. Kapteyn in the chair of astronomy at the University of Groningen and the directorate of the Kapteyn Astronomical Laboratory, van Rhijn contributed mainly to research on the stellar content and the interstellar matter of the Galaxy. Kapteyn had initiated and obtained wide international collaboration for his Plan of Selected Areas, aimed at exploring the structure and size of the Galaxy. Van Rhijn saw it as one of his primary tasks to realize this project and promote its extension. He encouraged and coordinated observational projects at observatories elsewhere and conducted extensive projects for the measurement of photographic plates at the Kapteyn Laboratory for both the study of proper motions and the measurement of stellar brightness. Among the main partners in these projects were the Harvard and Mount Wilson observatories in the United States and the Hamburg Observatory in Germany.

Besides these projects van Rhijn mainly worked on two aspects of galactic research: the distribution of stellar luminosity and the properties of the interstellar matter in the Galaxy. The first one resulted in the so called van Rhijn luminosity function that has for many years been the standard reference. It describes the frequency distribution of the absolute magnitudes – a measure of the star's intrinsic brightness – per unit volume in the solar neighborhood and is derived from careful analyses of the statistical distributions of stellar proper motions and apparent magnitudes. It was one of the starting points for the subsequent studies by other authors of the Initial Luminosity Functions [ILF] (also called "birth-luminosity function"). The ILF is then a guide to the distributions of masses of stars when they form, an important factor in the evolution of galaxies and their composition. The observed luminosity function determined from nearby stars can also be used to analyze counts of stars at larger distances to determine how stellar populations change with position in the Galaxy.

In his thesis of 1915, "Derivation of the Change of Colour with Distance and Apparent Magnitude," van Rhijn searched for a possible increase in the reddening of the apparent colors of the stars with increasing distance as evidence for the existence of interstellar matter, but the result was not conclusive. In later years, after the introduction of photoelectric measurements of stellar colors, he returned more successfully to this subject. Using the data on spectral classification for the Selected Areas that resulted from the joint project with the Hamburg Observatory, he determined the local density distribution separately for stars of different spectral classes.

During the occupation of the Netherlands in World War II (1940–1945) van Rhijn was hospitalized with tuberculosis but recovered fully, retiring only in 1957. He served as president of the Commission on Selected Areas (32) of the International Astronomical Union (1932–1958, one of the longest tenures of a single individual as Commission president) and as rector magnificus (vice chancellor) of Groningen University (1939–1940). Van Rhijn was elected a foreign associate of the Royal Astronomical Society (London), and was knighted by Queen Juliana of the Netherlands in 1956.

A nearly complete set of van Rhijn's publications, as well as many of his notebooks for lectures and research, are kept in the archives of the Kapteyn Institute of Groningen University.

Adriaan Blaauw

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Varāhamihira

Born **possibly Kapitthaka, (India), 505**
Died **Avanti, (Ujjain, Madhya Pradesh, India), 587**

Varāhamihira's three major works are *Pancha Siddhantika*, *Brihat Samhita*, and *Brihat Jataka*. The first of these summarizes the five important astronomical schools current at his time, the second is an encyclopedia, and the third is an astrological text. The *Pancha Siddhantika* presents the theories of the Paulisha, Romaka, Vasishtha, Paitamaha, and Surya Siddhantas. The *Brihat Samhita* has chapters on astronomy, geography, the calendar, meteorology, botany, agriculture, economics, engineering, zoology, and so on. Varāhamihira's main importance lies in his review of older astronomical theories, especially the Surya Siddhanta, and the description in his encyclopedia of the popular knowledge that existed in India during his time.

A. Vagişwari

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Vaucouleurs, Gérard Henri de

Born **Paris, France, 25 April 1918**
Died **Austin, Texas, USA, 7 October 1995**

Gérard de Vaucouleurs surveyed, classified, and cataloged galaxies in the Northern Hemisphere and Southern Hemisphere, and created a complex Galaxy classification system that differed from **Edwin Hubble**'s system and was more useful scientifically.

Vaucouleurs grew up in Paris. Nothing is known of his father; he adopted his mother's maiden name. Vaucouleurs showed a boyhood interest in astronomy, observing the Moon with a borrowed nautical telescope from the balcony of his family's apartment. With a telescope later given to him by his mother, he became an expert visual observer, timing lunar occultations and mapping the visible appearances of the planets. With his home-made map of Martian surface features, the young amateur astronomer measured the rotation rate of Mars with an accuracy unsurpassed until the 1960s Mariner spacecraft missions to the planet made further improvements possible.

Vaucouleurs studied astronomy, physics, mathematics, optics, photography, and spectroscopy at the University of Paris where he received an undergraduate degree in 1939. He joined amateur astronomer **Julien Péridier** at the latter's Le Houga Observatory to continue his planetary work, but the onset of World War II forced the closing of the observatory a few months later. Vaucouleurs served in the French army artillery for 19 months before the French capitulation in May 1941. He then returned to Le Houga, where in addition to continuing his lifelong studies of Mars, he took up double stars and variable stars. As a research scholar at the Sorbonne Physics Research Laboratory (1943–1945) and the Institut d'Astrophysique (1945–1950), Vaucouleurs earned a doctoral degree in 1949, defending a dissertation on molecular (Rayleigh) scattering and depolarization of light in liquids and gases. In 1944, he married Antoinette Pietra, an accomplished astronomer in her own right, who for the next 43 years would collaborate with him in many of his astronomical researches.

The Vaucouleurs immigrated to England where he was on the staff of the University of London's Mill Hill Observatory. In 1951 the couple moved to Australia when Gérard was awarded a fellowship to do planetary research at the Australian National University's Mount Stromlo Observatory. There he earned a second doctor of science degree, for research in molecular physics, optics, photography, astronomy, and astrophysics. During this time Vaucouleurs also served as observer-in-charge of the Yale–Columbia Southern Station in Canberra.

At Mount Stromlo, Vaucouleurs took advantage of the fact that the southern sky remained relatively unexplored by large telescopes or photography; little was known about the thousands of galaxies visible from the Southern Hemisphere. From 1952 to 1956 Vaucouleurs surveyed bright southern galaxies, and reobserved the 1,300 galaxies in the Shapley–Ames Catalog, measuring the brightnesses and radial velocities of hundreds of galaxies and determining their distances. Using his measurements, he mapped clusters of galaxies that aggregated to form what Vaucouleurs called the "Local Supercluster." In 1953 Vaucouleurs pointed out that most of the bright galaxies were distributed along a relatively narrow belt at an angle of roughly 90° to the plane of the Milky Way. He interpreted this distribution as the perspective effect of looking edge-on at a great disk of galaxies tens of millions of light-years across. At the time, few astronomers took Vaucouleurs's Local Supercluster model seriously. However, it is now generally accepted that galaxies are distributed in great sheets or bubbles of large-scale structure separated by large voids in intergalactic space.

From 1953 to 1956 Vaucouleurs made a detailed study of the Magellanic Clouds with **Frank Kerr**, discovering that the Milky Way's neighbors, previously regarded as irregular and chaotic in their form and motions, actually showed spiral structure and rotated. These studies resulted in the first accurate determination of the masses of the clouds; Vaucouleurs classified both clouds as barred spirals with a specific type of asymmetry. Vaucouleurs was also the first astronomer to classify the Milky Way as a barred spiral galaxy.

In 1957, Vaucouleurs came to the United States, where he would live for the rest of his life. After brief stints at the Lowell Observatory in Flagstaff, Arizona, and the Harvard College Observatory, Vaucouleurs joined the faculty of the University of Texas, Austin, in 1960. He became a naturalized citizen in 1962, and was named a full professor in 1965. At McDonald Observatory near Fort Davis, Texas, Vaucouleurs took photographs and made photometric and spectroscopic measurements of thousands of galaxies. For his survey, Vaucouleurs also designed and built a Fabry–Perot interferometer. With his data, he mapped the shape of the visible Universe with unprecedented accuracy, separating spiral galaxies according to their two major morphological components – the central bulge and the disk.

With his wife Antoinette and other collaborators, Vaucouleurs was an indefatigable cataloger of galaxies, publishing three *Reference Catalogues* of bright galaxies in 1964, 1976, and 1991 (the last published after Antoinette's death in 1987), and other valuable galaxy cataloges including databases of those objects that appeared in the southern sky. His catalogs were not mere compilations or lists, but contained much original data on angular sizes, magnitudes, colors, and radial velocities (redshifts) that Vaucouleurs gathered himself with the world's largest telescopes. He also applied a critical eye to data from other sources incorporated into his galaxy catalogs, carefully weighing it for its relative reliability.

Vaucouleurs devised a complex alternative to Hubble's scheme for classifying galaxies based on their morphologies. Vaucouleurs used many different parameters including the averaged surface brightness of the galaxy, its photometric brightness at different wavelengths, the ratio of the galaxy's HI content to its magnitude, and the ratio of a galaxy's central bulge to its disk. He developed formulae relating galaxies' angular dimensions to their luminosity profiles, discovering the "$r^{1/4}$" law that empirically defines the surface brightness distribution for elliptical galaxies.

Intensely interested in the cosmic distance scale – the absolute distances separating galaxies and clusters of galaxies in the Universe – Vaucouleurs questioned and revised the standard distance indicators and developed many new ones. He believed in spreading the risks by averaging the effects of many different distance indicators to cancel out systematic and statistical errors. Vaucouleurs' measurements of Galaxy distances led him to continue supporting a H_0 value near 100 km s^{-1} Mpc^{-1} (the majority view between about 1955 and 1970) after others had adopted values of 50–75. He was a propornent of hierarchical or fractal structure in the Universe, and of a non-zero cosmological constant, so that his large value of H was not in contradiction with the best estimates of the best estimates of the age of the Universe. His work and that of other proponents of the "short distance scale" (H_0 values in the range of 80 to 100 km s^{-1} Mpc^{-1}) stood in sharp contrast to the work of Allan Rex Sandage (born: 1926), Gustav Tammann, and others who favored values of H_0 nearer 50 km s^{-1} Mpc^{-1}, the "long distance scale." The precise value of H_0 remains somewhat uncertain in 2006, but seems to fall between 57 (Sandage) and 71 (Hubble Space Telescope key project).

Vaucouleurs received the Royal Astronomical Society's 1980 Herschel Medal and the American Astronomical Society's 1988 Henry Norris Russell Prize and lectureship. In 1986, he was elected a member of the United States National Academy of Sciences.

Vaucouleurs was survived by his second wife, the former Elysabeth Bardavid of Paris, France, whom he had known for a number of years and married in 1988.

Peter Wlasuk

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Verbiest, Ferdinand

Born **Pittem, (Belgium), 1623**
Died **Beijing, China, 28 January 1688**

Ferdinand Verbiest was a prominent Jesuit mathematician and astronomer who served the Chinese emperor. Born in West Flanders into a family of landed gentry, Verbiest received his secondary education in Bruges and Kortrijk and after a brief stay at the Arts Faculty of Louvain University (1640/1641), became a Jesuit novice of the Flemish–Belgian province in Mechlin (1641–1643). He returned to Louvain to complete his philosophical studies at the local Jesuit College, and finally obtained his degree in 1645. During a year's theological studies in Rome (1652–1653) at the celebrated Roman College, he made the acquaintance of the renowned scholar and mathematician, **Athanasius Kircher**.

In the second half of 1655 Verbiest received official permission to join the missionary group that was to set out for China under the leadership of M. Martini. When the group was forced to spend a year in Portugal, Verbiest was sent to Coimbra to teach mathematics, an indication that he was already developing a reputation as a mathematician. From Portugal he maintained his contacts with Kircher in Rome and managed to obtain some of Kircher's recent works. The group finally set sail and reached Macao, the gateway to the Chinese mainland, on 17 July 1658. Verbiest's practical schooling in astronomy apparently continued during the voyage, with Martini as his teacher. In Macao he acquired his first knowledge of Chinese by reading the Four Confucian Classics.

Verbiest was first sent to Hsi-an-fu in the Shensi province where, despite his still deficient command of the Chinese language, he performed the work of a simple missionary with great enthusiasm. On 26 February 1660 **Johann Adam Schall von Bell**, with the endorsement of the Shun-chih emperor, called him to Beijing. Schall von Bell saw Verbiest as a possible successor to the very important position Schall von Bell held as head of the Astronomical Bureau, where he had the ultimate responsibility for the annual calendar. Schall von Bell undoubtedly chose Verbiest because of his fame as a mathematician. That his reputation as a mathematician had already penetrated into China at this early stage of the mission is explicitly attested by various correspondence in those years between Beijing and Rome. Upon his arrival in Beijing on 9 June 1660, Verbiest was received by Schall von Bell in the Hsi-t'ang residence where he was initiated and prepared for his future task as head of the Astronomical Bureau, primarily of its calendar section. Also in these initial years Verbiest was active in more areas than specifically required for the calendar. As early as 1661 and 1662 he assisted Schall von Bell in the difficult task of hanging an enormous clock in the Beijing Bell Tower with the aid of pulleys, and he had produced a series of drawings for new astronomical instruments based on the system of **Tycho Brahe**.

In 1664 Yang Kuang-hsien launched an outright attack against the western influences within the Chinese Astronomical Bureau, in particular against the unquestioned application by the Jesuits since 1644 of the "western rule" in the establishment of the annual calendar. After several failures Yang Kuang-hsien, taking advantage of the altered climate since the death of the Shun-chih emperor (1661) and of the anti-western mood under the so called Oboi regency (1661–1669), seized his opportunity. A legal complaint was filed, and the Jesuits were arrested, put on trial, and convicted. During these particularly trying times Verbiest displayed great devotion towards his half-paralyzed mentor, Schall von Bell, who died on 15 August 1666.

After the conversion of the initial death sentence to house arrest, and after the banishment of 25 Jesuits to Canton, Verbiest with several Jesuit companions spent 4 years (1665 to 1669) under surveillance in the Tung-Vang residence. During this time he managed to show his skill at forecasting solar eclipses, and he occupied himself with the construction of mechanical devices, with experiments in steam-powered vehicles, with tests of gnomons, and with meteorological observations. Here we see Verbiest, under house arrest, preparing himself as the many-sided engineer and mathematician, who from 1669 would serve the emperor in a wide variety of mathematical and mechanical disciplines. By his prediction and verification of planet positions and by his successful tests of gnomons, Verbiest convinced the emperor of his thorough command of western astronomical science. He thus managed to have the “western rule” of calendar making reinstated, and himself along with it.

Verbiest was soon appointed by the Ministry of Rites to the position of prefect of the Astronomical Bureau, a title he was to hold until the end of his life. From the position that office provided him, he would henceforth develop an uncommonly busy and varied activity. The services he rendered to the emperor, to some Chinese officials, and to China, in fact, made him indispensable, a situation accordingly recognized in the form of distinctions of all kinds that quite rapidly elevated him to the second rank of the mandarin hierarchy in 1676.

A survey of the writings of that period also reveals Verbiest’s missionary activity, particularly in the form of several treatises on points of religious belief. His principal contribution in this area, however, consisted in maintaining the emperor’s friendship by performing his manifold tasks, thus protecting the mission in the rest of China. In addition he was active as a diplomat, for example, in the Sino–Russian negotiations concerning the Amour frontier. By designating a competent successor, as well as by attracting French Jesuits in 1685, Verbiest also ascertained the survival of the mission. His death prevented him from witnessing the realization of two important aims for which he himself had laid the groundwork: the treaty of Nerchinsk on 28 January 1689, establishing peace between China and Russia along the Amour River, and the K’ang-hsi edict of 1692, guaranteeing a far-reaching toleration for Catholicism.

George V. Coyne

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Very, Frank Washington

Born **Salem, Massachusetts, USA, 12 February 1852**
Died **Massachusetts, USA, 23 November 1927**

Frank Very was an 1873 graduate of the Massachusetts Institute of Technology. He was employed at, or associated with, successively, the Allegheny, Lowell, and Westwood observatories. Very assisted two of the best-known figures in late-19th-century American astronomy: **Samuel Langley** and **Percival Lowell**. He was recognized in his own right for investigating the lunar albedo bolometrically.

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Vespucci, Amerigo

Born **Florence, (Italy), 18 March 1454**
Died **Seville, Spain, 22 February 1512**

New World navigator Amerigo Vespucci was born into one of the leading mercantile, aristocratic families of Florence. He demonstrated in 1501 and 1502 that the lands discovered in 1492 by Christopher Columbus were continental in extent, ascertained a longitude by means of a lunar occultation of the planet Mars, and gave both findings wide publicity.

Vespucci studied under a student of the Italian astronomer **Paolo Toscanelli**, and enjoyed the support of an established mercantile network – providing supplies and services for Columbus himself in the process. In 1499 and 1502 Vespucci used the *Ephemerides* of **Johann Müller** (Regiomontanus) the leading European authority, to determine his longitude.

Attempting to explain to a general audience the navigational problems in determining longitude at sea, Vespucci wrote:

> I found nothing better to do than to watch for and take observations at night of the conjunction of one planet with another, and especially of the conjunction of the moon with the other planets. . . . One night, the twenty-third of August, 1499, there was a conjunction of the moon with Mars, which according to the almanac [for the city of Ferrara] was to occur at midnight or a half hour before. I found that when the moon rose an hour and a half after sunset, the planet had passed that position in the east. (quoted in Boorstin, 1991, p. 357.)

The difference in longitude between the two locations was then the same as the difference in the observed times of this event.

Vespucci was included in a Spanish expedition of 1499 and served as a leader of an expedition to the coast of Brazil sponsored by King Manuel I of Portugal, in 1501 and 1502. Vespucci's accounts of his travels, written in evocative, sometimes poetic terms, won a wide readership. The community of Florence ordered the illumination of the Vespucci mansion in celebration of his announcement, following the 1501/1502 voyage, that the western lands were an entire continent. Latin, French, German, and Dutch translations of his *Mundus Novus* appeared rapidly, and in many reprintings. A printed atlas with an edition of Vespucci's letters appeared in 1507, containing a map labeling the New World "America."

Michael Meo

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Vico, Francesco de

Born **Macerata, (Marche, Italy), 19 May 1805**
Died **London, England, 15 November 1848**

Comet hunter father Francesco de Vico became a Jesuit in 1823 and joined the faculty of the Collegio Romano. In 1833 he began his studies in astronomy and started his observations of comets 1P/Halley and 3D/Biela. In 1838 de Vico became director of the observatory in the Collegio Romano. After making planetary observations (Mimas, Enceladus, Saturn, and Venus) he discovered seven comets between 1844 and 1847. Apart from his work in astronomy, he was active in helping the sick during the 1837 cholera epidemic. The unrest during 1848 forced de Vico to leave Rome and go to the United States as a refugee.

Mariafortuna Pietroluongo

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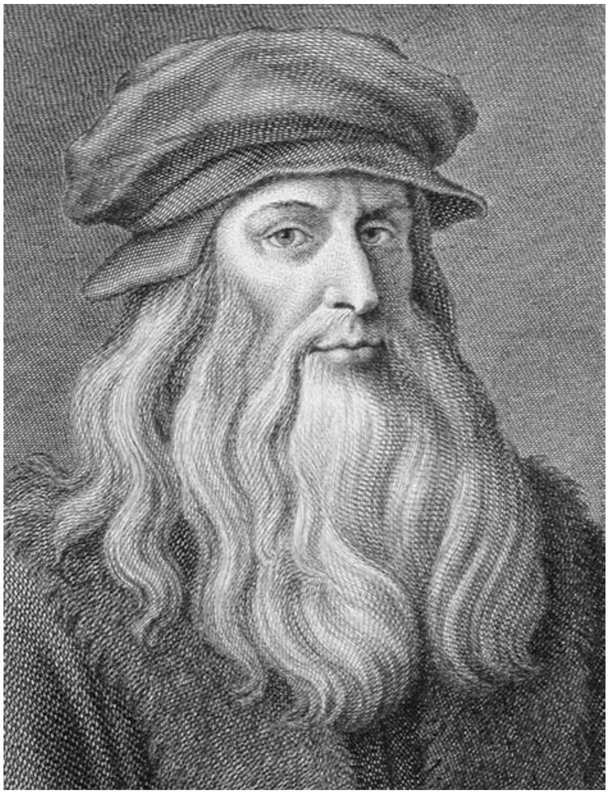
Vinci, Leonardo da

Born **Florence, (Italy), 15 April 1452**
Died **Cloux, near Amboise, (Indre-et-Loire), France, 2 May 1519**

Artist Leonardo da Vinci, of Florence and Milan, produced three naked-eye renderings of the Moon. He thought of the Earth's satellite as a nonuniform mirror (likely watery with some land) reflecting the light of the Sun. Knowing that a smooth sea would result in a specular reflection, da Vinci imagined white-capped waves breaking on lunar shores. He also correctly identified "earthshine" as being produced by sunlight reflected from the Earth to the Moon.



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Virdung, Johann

Born **Hassfurt, (Bavaria, Germany), 14 March 1463**
Died **Heidelberg, (Germany), 1538/1539**

Johann Virdung was one of the most influential astrologers around 1500. Virdung, about whose childhood and youth nothing is known, began his studies in 1481 in Leipzig, and continued them in Krakow, where he attended (*inter alia*) the lectures by **Albertus de Bruzewo** and Johannes von Glogau. He returned to Leipzig as "Johannes Johannis baccalaureus Cracovensis," where he obtained his master's degree in 1491. The following year Virdung moved to Heidelberg, where he gave lectures on medicine, mathematics, and astronomy at the university and entered the service of the Electoral Palatinate court. From 1521 until his death he ran the court dispensary; and around 1529/1530 he was conferred a medical doctorate. In 1487, his first (or the earliest so far known) of his prognostications appeared in Leipzig; his bibliography includes at least 80, generally minor, astrological works in German and Latin, but also medical books.

Virdung compiled numerous almanacs, annual astrological forecasts, and interpretations of special celestial events. His annual prognostications followed the traditional pattern: the determination of the ruling planet for the year, the prediction of weather conditions, the prospects for the harvest, and the determination of the time for carrying out medical procedures, as well as the interpretation of eclipses. Particularly widespread were Virdung's writings about the Great Conjunction of 1524, which appeared in Latin in 1521 and in both 1522 and 1523 in German, and in which he endorsed the general predictions for multiple disasters in that year. These prophecies on the eve of the great German Peasants' War reflected the tense social situation in the first-third of the 15th century. Virdung used astrological prophecies in the hope that reforms would be introduced into the church, that serious shortcomings in the Church would cease, and that neither the nobles nor the "common folk" would rebel against the clergy.

Virdung's great standing in the scholarly world is shown by the fact that he was asked, on behalf of Heidelberg University, to present a report to the Lateran Council (1512–1517) regarding the planned calendar reform (which was, however, not implemented).

Virdung's lesser astrological works were extremely popular, which is partly shown by the numerous editions in Latin, German, and Low German, printed in Leipzig, Nuremberg, Lübeck, Oppenheim, Stendal, and Strasbourg with the same work often appearing in several places. After Virdung's death, some of his predictions were reproduced in various collections of astrological prophecies. His observations of optical phenomena (haloes that appeared around the Sun and Moon) show that apart from Virdung's interpretations of them as miraculous, he had genuine powers of observation.

Of his major works, Virdung's *Tabulae resolutae* must be mentioned. This was published in 1542, after the author's death, by his pupil Jacobus Curio. The foreword contains important information about Virdung. There was also an iatromathematical work on the astrological basis for medicine, *Novae medicinae methodus* (1532, second edition, 1533), in which he complains that doctors disregard astrology, and that he hoped to give doctors reliable assistance with this book.

Jürgen Hamel

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Virgil [Vergil]

Born **Andes, Cisalpine Gaul, (Lombardy, Italy), 15 October 70 BCE**
Died **Brundisium (Brindisi, Italy), 20 September 19 BCE**

The Roman poet Virgil adapted and incorporated traditional themes and earlier literary treatments of astronomy into his own works. According to ancient accounts and evidence from his poems themselves, Virgil, the most illustrious of Latin poets, was born in the small village of Andes near Mantua in the Po Valley region of Italy. Details of his family circumstances and childhood are uncertain, but he seems to have been educated at Cremona and later at Milan before going to Rome. He also spent time in Naples, where he associated with the Epicurean philosophical community there. In 42 BCE after the victory of Octavian (later the emperor Augustus) in the civil war that followed the assassination of Julius Caesar, Virgil's family property was confiscated to settle veterans but subsequently restored. After the publication of his earliest poems (*circa* 38 BCE) Virgil was invited to join the circle of Maecenas, an intimate friend, and advisor to Octavian. Thereafter he, received official support for his poetry, and in turn generally promoted the policies of the regime in his works. He associated with the leading literary and political figures of his day until his death. From the outset, Virgil's literary influence has been enormous.

Of a number of works ascribed to Virgil by commentators ancient and modern, only three, all written in epic hexameters, can be deemed genuine. The earliest of these works are the *Eclogues*, a collection of 10 individual poems styled after the pastorals of the Greek poet Theocritus. The four books of the *Georgics*, published in 29 BCE, comprise a structurally complex and multifaceted poem, ostensibly modeled on **Hesiod**, whom Virgil acknowledges (*Geo.* 2.176), but drawing inspiration as well from **Aratus** and a host of other Greek and Roman writers. It is superficially about the order and unity of the agricultural world, but in reality poses unsettling questions about cosmic and societal ambiguity and ambivalence. Virgil's final work, left unfinished at his death and edited for publication at the behest of Augustus, is the *Aeneid,* the Roman national epic, consciously suffused by its author with Homeric details, references, and literary echoes. The *Eclogues* and the *Aeneid* make general reference to the workings of the heavens in a number of passages; in the *Georgics,* especially Books 1 and 2, Virgil focuses directly on both the traditional and the literary functions of astronomy. Although each work differs markedly in its general theme and content, taken together they reveal the poet's awareness of the skies and a studied familiarity with the literary heritage of astronomical writing.

Virgil acknowledges that for the scientific aspects of astronomy, other peoples, specifically the Greeks, are better suited than the Romans (*Aen.* 6.849-51). In Virgil's view, too, the stars represent one element of the opposition between the two cultures. Yet he honors the Greek intellectual achievement by naming the Alexandrian astronomer **Conon** and by alluding to another, probably **Eudoxus** (*Ecl.* 3.40-42), even though for the Romans astronomy was primarily of practical value in its application to the agricultural year and, later, for navigation. A comprehensive Virgilian cosmogony appears in *Eclogue* 6, where the satyr Silenus describes the beginnings of things (31-40) in language suggestive of **Lucretius**'s Epicureanism. Virgil's recounting of the themes sung by the bard Iopas (*Aen.* 1.742–6), incorporating as they do the mention of commonly known constellations and celestial occurrences, represents his awareness of larger cosmic concerns.

Even in a primarily literary environment, much astronomical material is evident in Virgil. For example, he identifies five celestial zones and their terrestrial counterparts (*Geo.* 1.231–58), closely following several earlier writers, especially **Eratosthenes**. The description likewise presupposes a geocentric universe (242–3). The poet also describes the Sun's passage through the 12 signs of the zodiac (231–2), although he names only six anywhere in his works. Virgil values a general knowledge of the heavens (*Geo.* 1.1; 2.1; 2.475–82) and also recognizes the ancient observances of the risings, settings, and daily motions of the heavenly bodies (*Ecl.* 9.49, *Aen.* 3.515), including both the morning star, Lucifer (*Ecl.* 8.17; *Geo.* 3.324), and its evening counterpart, Vesper (*Ecl.* 6.86; *Geo.* 1.251; 3.337). The movements of the planets, the Sun, and the Moon provide a source of insight (*e. g.*, *Geo.* 1.337; *Aen.* 1.742), while lunar and solar weather signs form an important part of the *Georgics* (1.351–463). Significant also are eclipses (*Geo.* 1.467; 2.478; *Aen.* 1.742), which the poet relates to terrestrial affairs, and comets (*Geo.* 1.365–67, 488; *Aen.* 5. 527–28; 6.693–4; 10.272), which had portentous status in antiquity. The famous Sidus Iulium, a comet that marked the ascent of Julius Caesar as a divinity after his death, appears in Virgil's early works (*Ecl.* 9.46–9) as a source of abundance and later figures prominently on the pro-Augustan iconography depicted on the shield of Aeneas (*Aen.* 8.681).

The stars themselves seem to generate both knowledge and wonder, as when the pilot Palinurus is depicted gazing upward at them (*Aen.* 5.25, 853). As might be expected in a body of work drawing extensively on an earlier epic tradition, Virgil refers to the constellations of **Homer** and Hesiod on several occasions: the Great Bear (Arctos), the Pleiades, and the Hyades (*Geo.* 1.138; cf. 1.246, 4.231–5); the two Bears (Triones) (*Aen.* 1.744; 3.516); and Orion (*Aen.* 1.535, 3. 517, 4.52, 7.719). The stars Arcturus (*Geo.* 1.68, 204; *Aen.* 1.744, 3.516) and Sirius (*Geo.* 4.425; *Aen.* 3.141. 10.273) are mentioned as well. Other constellations, primarily from Aratus and agricultural works, appear in the farmer's calendar section of the *Georgics* (1.204–30) and in its description of the great Celestial Sphere (1.231–58). Here Virgil describes how Draco, the Haedi, Boötes, Corona Borealis, Canis Major, Libra, and Taurus serve as astronomical markers for farming tasks. Elsewhere, he recognizes several additional zodiacal constellations, including Cancer (*Ecl.* 10.68), Aquarius (*Geo.* 3.304), Virgo (*Geo.* 1.33), Scorpius (*Geo.* 1.35), and perhaps Pisces (*Geo.* 4.234). The Virgilian creation of Libra from the claws (Chelae) of the Scorpion (*Geo.* 1.33–35) reveals the wedding of the astronomical and literary spheres to contemporary politics in its praise of Augustus, initiating a general tendency of linking Roman rulers to the heavens that would continue to develop in imperial culture. A number of passages suggest traces of astrological tendencies in Virgil's works as well, particularly as evident in the phrase "stars aware of fate" (*Aen.* 4.519–20, 9.429) and in references to mortals who possess a special insight into the heavens (*Aen.* 3.359–60, 10.176). In later ages, of course, Virgil himself was considered a seer and magician, and his works were consulted as an oracular source of knowledge of the future.

John M. McMahon

Alternate name

Vergilius Maro, Publius

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Vergilius Maro, Publius

➔ **Virgil [Vergil]**

Vitruvius, Marcus

Born **Fundi (Fondi, Campania, Italy), *circa* 85 BCE**
Died ***circa* 15 BCE**

Vitruvius is best known for his writings on architecture, but he also wrote on astronomy, describing the understanding of his time and its usefulness in making sundials.

Vitruvius was born amid the death throes of the Roman Republic to an old South Italian family prominent at Fundi (midway between Rome and Naples). Trained in architecture, as a young man he served in the army corps of engineers under Caesar, first in Gaul (known service includes Larignum 56 BCE and Marseilles 48 BCE), then in North Africa (at Zama in 46 BCE). After his general's assassination, Vitruvius joined the troops of Octavian (the future Augustus), on active duty as an artillery engineer; by 33 BCE he was an aqueduct official.

Vitruvius wrote one known work, a handbook (*institutio*) in ten books on "architecture" – that is civil engineering – from selection of a city site through design and construction to maintenance and defense. He gives extensive theoretical justifications for each precept, devoting over two-thirds of Book 9 to astronomy and astrology, as the basis for constructing sundials. He wrote for many years around 25 BCE, in his old age and during peacetime.

Vitruvius offers no original astronomy, but summarizes contemporary belief and preserves some otherwise lost astronomy. Short shrift but no polemics is given to astrology (recently popular). Constellations visible in Rome are described from a star map based on **Aratus**' poem (possibly using **Hipparchus**' commentary). Annual solar motion causes seasonal phenomena, especially variable day length, with equinoxes and solstices occurring at 8° of Aries, Leo, Libra, and Capricorn. Vitruvius gives two explanations of lunar phases: **Aristarchus** of Samos thought moonlight was reflected sunlight, the phases being explained by geometry, while **Berôssus** of Babylonia claimed the luminous lunar hemisphere is attracted by sunlight which rotates the Moon. The Vitruvian universe is standard for the era, described in mechanical terms: the heavens rotate about the Earth on pin-like poles beyond the stars, round which wheel rims roll as on a lathe (*tornus*). In orbits contrary to the stars, the Moon, Mercury, Venus, the Sun, Mars, Jupiter, and Saturn (the standard order) "wander" from west to east, one above another "as if on a staircase."

For the planets outside the Sun, Vitruvius gives the most accurate ancient solar periods: Mars 683 days (4 days less than the modern value), Jupiter 11 years, 313 days (2 days less), and Saturn 29 years, 160 days (7 days less). He explains their apparent retrogradations through an alleged greater attraction by solar rays at greater distances. Vitruvius offers a heliocentric model for Mercury and Venus in which the Sun's rays serve as a center that those planets "crown," their varying speeds being explained by their varying distance from the attractive Sun.

Vitruvius bases his architectural theory primarily upon Hermogenes of Alabanda (*circa* 160 BCE) and earlier Greeks, attributing authority to Antiquity (*e. g.,* Aratus, Aristarchus, Berôssus, and Ktesibius – all 3rd century BCE), the latest astronomer cited being Hipparchus. Since the partially heliocentric theory presumes epicycles, it postdates **Apollonius**, and probably Hipparchus (whom **Ptolemy** alleges attempted no planetary theory). One may suspect the heliocentrist **Seleukus** or perhaps the neopythagorean astronomer Apollonius of Mundos, who theorized that comets were long-period planets on elongated orbits.

Paul T. Keyser

Alternate name

Pollio, Marcus

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Vogel, Hermann Carl

Born **Leipzig, (Germany), 3 April 1841**
Died **Potsdam, Germany, 13 August 1907**

German observational astronomer and spectroscopist Hermann Vogel was the first person to recognize a spectroscopic binary, that is, a pair of stars that reveal their mutual orbit through changes of their velocities along the line of sight *via* a changing Doppler shift of their spectral features. He was the sixth child of a Leipzig educator, Carl Christophy Vogel, and grew up in a family that valued intellectual pursuits. His older brother Eduard's friendship with the director of the Leipzig Observatory acquainted him with astronomy early on in his life. In 1860 Vogel attended the Dresden Polytechnic School to prepare for a career in technology. However, during his studies, his parents died, leaving him without financial support. He worked himself out of debt, partly through teaching the new technology of photography, and returned to Leipzig in 1863 to study natural science and work as an assistant at the

university's observatory, working under **Karl Bruhns**. Vogel earned his doctorate in 1868 for observations of the positions of nebulae and star clusters and a historical survey of nebular observations.

In 1870, Vogel was given the directorship of the private observatory of F. G. von Bulow in Bothkamp. There Vogel began a research program of spectroscopic observations of the Sun, stars, planets, nebulae, and even lightning and aurorae. He was one of the first professional astronomers to use photography to enhance the accuracy of observations. His paper on the spectra of planets won a prize from the Copenhagen Academy of Sciences and was regarded as an authoritative work for decades after its publication. Based on his spectral observations of stellar bodies, Vogel proposed modifications to **Angelo Secchi**'s classification scheme for stellar spectra. Utilizing Doppler shifts of spectra to infer velocities, he observed the rotation of the Sun, establishing that the photosphere rotates at the same rate as previous sunspot observations indicated.

Intrigued by the attempts of **William Huggins** to determine the line-of-sight or radial velocity of fixed stars, Vogel took up the problem and started making visual observations of a few stars. Around this time, the Prussian state decided to build an observatory in Potsdam, and Vogel was asked to be an observer and to help plan the equipment needs of the new observatory. The Potsdam Astrophysical Observatory was finished in 1879, and Vogel was appointed director in 1882, a position he held until his death. With the new facilities available to him Vogel was able to make real progress on his studies, and in 1892, he published the first accurate observations of the radial velocities of 51 stars.

One of the most striking achievements of the radial velocity study was the discovery of spectroscopic binaries. These are pairs of stars too close together to be seen as separate images. Vogel showed that Algol and Spica are binaries. For the former, this explained the periodic brightness fluctuations first found in 1669, and it confirmed an explanation put forward in 1783 by **Charles Goodricke**, that one star was passing in front of the other. At nearly the same time, **Edward Pickering** at Harvard College Observatory announced that Mizar and β Aurigae were also spectroscopic binaries, the latter having been recognized by **Antonia Maury**. About half of all stars are binaries, and the fraction detectable as such by spectroscopic measurements increases with the accuracy of the velocity measurements. The combination of the velocity measurements and eclipse light curve for Algol enabled Vogel and **Julius Scheiner** to make the first estimate of the mass of a body outside the Solar System.

As time went on, Vogel spent increasing amounts of time on organizational duties and securing upgrades to observational equipment. His management of the Potsdam Astrophysical Observatory helped to make it an important and productive center for research, and he was highly regarded for getting the most out of the equipment he had. Among his many honors and memberships in learned societies, the following stand out: In 1892 Vogel was elected to the Berlin Academy of Sciences, in 1893 he won the Gold Medal of the Royal Astronomical Society, and in 1906 he won the Bruce Medal of the Astronomical Society of the Pacific. Vogel died after several years of failing health.

Michael Fosmire

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Vögelin, Johannes

Flourished **(Austria), 16th century**

Viennese astronomer Johannes Vögelin attempted to measure the parallax for the comet of 1532 (c/1532 R1).

Alternate name

Vogelinus

Selected Reference

Hellman, C. Doris (1944). *The Comet of 1577: Its Place in the History of Astronomy.* New York: Columbia University Press, 1944. (Reprint, New York: AMS Press, 1971.)

Vogelinus

➔ **Vögelin, Johannes**

Vogt, Heinrich

Born **Gau-Algesheim, (Rheinland-Pfalz), Germany, 5 October 1890**
Died **Heidelberg, (Germany), 23 January 1968**

Heinrich Vogt and collaborators solved problems of the internal structure of stars, origin of spiral arms in galaxies, and the redshift in cosmology.

Vogt was born in a family of farmers headed by Philipp and Margarete Vogt, in a small town near Mainz am Rhein. The Gymnasium in Mainz and the university in Heidelberg prepared him well for the career of a professional astronomer. Soon after beginning university studies (1911) he started routine observations at the Heidelberg-Königstuhl Observatory under supervision of the director **Maximilian Wolf**, who appointed him as his assistant in the next year. Vogt was attracted more to theory than to observations. After an interruption to his studies due to World War I he graduated in April 1919.

Vogt's thesis dealt with the interpretation of observed properties of stars, including limb darkening, reflection of light in binaries, and distortions of the shapes of binary stars by their companions. His subsequent work at the observatory on the photometry of variable stars, comets, novae, and star clusters (especially h and χ Persei) resulted in his appointment to an associate professorship at the university.

Vogt continued theoretical investigations on the internal structure of stars, communicating with **James Jeans**, **Arthur Eddington**, and **Edward Milne**, who became his close friend. Vogt concluded in 1926 that the internal structure of a star was completely fixed by its mass and chemical composition. This is called the Vogt–Russell theorem in Europe and the Russell–Vogt theorem in the United States. It remains true for the evolution of a star of homogeneous composition, but the theorem fails when, for instance, the star develops an exhausted helium core. In the same year, Vogt obtained positions as assistant professor at Heidelberg University and observer at the observatory.

Vogt spent 3 years (1929–1932) in Jena as full professor and director of the Jena Observatory. For the first time he had freedom to develop the institute according to his plans. Soon his group of collaborators and students received international recognition in theoretical astrophysics.

After the death of Wolf in 1932, Vogt returned to Heidelberg and became director of the observatory and professor at the university. He refused an invitation to the Potsdam Astrophysical Observatory and continued his theoretical investigations of stellar interiors even though he was forced to manage a lot of organizational work at both institutions. After the end of World War II, in 1946, Vogt resigned the directorship at the observatory but increased his teaching activities in Heidelberg and Stuttgart (as visiting professor). He also began to write popular books on astronomy and cosmology.

Vogt was a member of the academies in Heidelberg, Berlin, and Halle.

Martin Solc

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——— (1946). *Die Spiralnebel*. Heidelberg: C. Winter.

——— (1949). *Der Bau des Weltalls*. Stuttgart: C. E. Schwab.

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——— (1961). *Die Struktur des Kosmos als Ganzes*. Berlin: Morus-Verlag.

——— (1964). *Das Sein in der Sicht des Naturforschers.* Berlin: Morus-Verlag.

Volkoff, George Michael

Born **Moscow, Russia, 23 February 1914**
Died **Vancouver, British Columbia, Canada, 24 April 2000**

Working with **Julius Robert Oppenheimer**, in 1939, Russian–Canadian physicist George Volkoff calculated properties of a star supported by the pressure of neutron degeneracy. Such an object eventually would be called a neutron star.

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Oppenheimer, J. R. and G. M. Volkoff (1939). "On Massive Neutron Cores." *Physical Review* 55: 374–381.

Vorontsov-Veliaminov [-Velyaminov], Boris Aleksandrovich

Born **Dnipropetrovs'k, (Ukraine), 14 February 1904**
Died **Moscow, Russia, 27 January 1994**

Boris Vorontsov-Veliaminov was a prolific researcher, devoted pedagogue, and writer on a variety of astronomical subjects. He was the author of a standard astronomy textbook for high school students that, over many decades, passed through numerous editions. His books crafted for general readers attracted several generations of future astronomers. Starting in 1947, Vorontsov-Veliaminov was the only Soviet astronomer who was elected a corresponding member of the Soviet Academy for Pedagogical Science. His disciples at various levels in the former Soviet Union were almost numberless. Like **Nicolas Flammarion** in France, Vorontsov-Veliaminov in the Soviet Union was the foremost of astronomical promoters during his lifetime.

Vorontsov-Veliaminov graduated from Moscow University in 1925, where he conducted research throughout his life at the Sternberg State Astronomical Institute. He was appointed a professor of astronomy in 1934. His scientific contributions spanned a range of astrophysical topics, including "early-type" stars, diffuse and planetary nebulae, novae, and irregular galaxies.

Independently of **Robert Trumpler**, Vorontsov-Veliaminov argued (1929/1930) for the absorption of starlight in the Galaxy, although he did not provide a value for the amount of absorption (which Trumpler soon supplied). Nonetheless, his skepticism toward models of the Galaxy that neglected interstellar absorption was later vindicated.

With a team of collaborators, Vorontsov-Veliaminov published two atlases and catalogs depicting several hundred interacting galaxies (1959 and 1970). Under his guidance, detailed morphological descriptions of some 32,000 galaxies were published between 1962 and 1974. Vorontsov-Veliaminov argued, incorrectly, that magnetic fields, rather than gravitational (tidal) interactions, were chiefly responsible for the filaments and "tails" observed.

A very gentle person, Vorontsov-Veliaminov tried to do his best as an administrator when necessary. He was imprisoned for a short time under Josef Stalin's regime. Vorontsov-Veliaminov wrote extensively on the history of astronomy in Russia and the USSR and composed a memoir on astronomy in Moscow after the 1917 Bolshevik Revolution. He was awarded the Bredikhin Prize of the Academy of Sciences in 1962.

Alexander A. Gurshtein

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Vorontsov-Veliaminov, B. A. and A. A. Krasnogorskaya. (1962–1974). *Morfologicheskii katalog galaktik* (A Morphological Atlas of Galaxies). Moscow: Izd-vo Moskovskogo Universiteta.

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Voytekhovich, Marian Albertovich

➜ **Kovalsky, Marian Albertovich**

W

Wābkanawī: Shams al-Munajjim [Shams al-Dīn] Muḥammad ibn ˁAlī Khwāja al-Wābkanawī [Wābkanawī]

Flourished **(Iran), early 14th century**

Wābkanawī is the author of the important astronomical handbook *al-Zīj al-muḥaqqaq*, which contains valuable historical information on lost earlier works and is one of only two *zīj*es known to be based on the observations carried out at the famous observatory at Marāgha.

Wābkanawī presumably hailed from the village Wābkana (or Wābakna) nearly 20 km from the important cultural center of Bukhara (now in Uzbekistan). Hardly anything is known about his life, and the available information about his astronomical career derives mainly from his astronomical handbook with tables, *al-Zīj al-muḥaqqaq al-sulṭāni ˁalā uṣūl al-raṣad al-Īlkhānī* (The correct *zīj* for the sultan based on the principles of the Īlkhān observations). From the introduction to this work it appears that Wābkanawī made observations during a period of 40 years, presumably at the famous observatory in Marāgha in northwestern Iran, which had been founded by Hülegü Khān at the instigation of **Ṭūsī** in 1258. However, Wābkanawī was also involved in the reform of the Malikī calendar ordered by Maḥmūd Ghāzān Khān (reigned: 1295–1304), who had an observatory built in Tabrīz. It is therefore possible that Wābkanawī spent part of his career in Marāgha and part of it in Tabrīz.

The *Zīj* of Wābkanawī is extant in four or five manuscript copies, of which no. 2694 of the Aya Sofia Library in Istanbul is the most complete. The work is written in Persian even though the title given above (found on f. 4a of the Aya Sofia manuscript) is in Arabic. Wābkanawī started working on the *Zīj* under Öljeytü Khān (reigned: 1304–1316) and finally dedicated it to Abū Saˁīd (reigned: 1316–1335). It consists of five treatises (*maqāla*s) dealing in a very extensive way with all the standard topics of *zīj*es, in particular chronology, planetary positions and eclipses, spherical astronomy, and timekeeping.

Only scattered parts of the work have been studied. The introduction is important because it mentions a number of earlier *zīj*es that are nonextant and not known from earlier sources; these include, in particular, the six *zīj*es of al-Fahhād.

The chronological chapter of the *Zīj* describes the reform of the Malikī or Jalālī calendar carried out on the order of Maḥmūd Ghāzān Khān in 1302. The original calendar had been adopted by the Seljuk Sultan Malikshāh I in 1079. Wābkanawī and various other astronomers appointed by Ghāzan Khān modified the exact definition of the beginning of the year (*i. e.*, the day of the vernal equinox), adopted a new epoch called "Khānī," and introduced the use of Turkish month names. Wābkanawī writes that he adopted the new calendar in his *Zīj*, although he uses the year 188 Malikshāh (1266) as epoch, possibly in order to cover the dates of observations made at Marāgha. Wābkanawī also presents an extensive explanation of the Chinese–Uighur calendar that was introduced into Iran by the Mongols and first described in the *Īlkhānī Zīj* of Naṣīr al-Dīn al-Ṭūsī.

The present author has made a cursory analysis of the planetary tables in *al-Zīj al-muḥaqqaq*. The mean motions were shown to have been derived from those in the *Adwār al-anwār*, the latest of the three *zījes* by **Ibn Abī al-Shukr al-Maghribī** and known to be based on the extensive observational program carried out by that astronomer at Marāgha. Most of Wābkanawī's tables for the planetary equations were simply copied from the *Adwār*.

A work by Wābkanawī on the astrolabe, the *Kitāb-i maˁrifat-i usṭurlāb-i shamālī* (On the northern astrolabe), likewise in Persian, is extant in a manuscript in the library of the Topkapı Saray Museum in Istanbul. It consists of two chapters: one on the parts of the astrolabe and one on the operations with it. An Arabic fragment by Wābkanawī on the difference in setting times of the Sun and the Moon is extant in Cairo.

Benno van Dalen

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Sayılı, Aydın (1960). *The Observatory in Islam*. Ankara: Turkish Historical Society.
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Wachmann, Arno Arthur

Born **Hamburg, Germany, 8 March 1902**
Died **Hamburg, (Germany), 24 July 1990**

German observational astronomer Arno Wachmann is most likely to be recognized for his discovery of several comets, jointly with **Arnold Schwassmann**, although most of his work was in stellar statistics and variability. Wachmann studied astronomy in Kiel and obtained his Ph.D. degree under **Carl Wirtz** in 1926. His dissertation concerned the proper motions of some 8,800 stars. After a short time at the Remeis Observatory in Bamberg, Germany, Wachmann returned to Hamburg in July 1927, remaining there until his retirement on 31 March 1969. His position there began as a scientific assistant to Schwassmann, and he then became a scientific advisor, department chief, and finally, a senior observer. In 1961, he was appointed an honorary professor at the University of Hamburg. As a result of an invitation by Walter J. Miller, Wachmann worked at the Fordham Astronomical Laboratory in New York, USA, in 1958 and again in 1961/1962.

Much of Wachmann's work concerned an international program to investigate the statistics of stars over the entire sky. Together with Schwassmann, he worked on the Bergdorf spectral survey whereby the brightnesses, colors, spectral types, and proper motions of stars were observed over various sky regions with particular attention given to certain calibration fields, the Selected Areas of **Jacobus Kapteyn**. It was during these stellar surveys that Schwassmann and Wachmann discovered four comets. These comets, three of which are periodic, were 29P/1927 V1 (Schwassmann–Wachmann), 31P/1929 B1 (Schwassmann–Wachmann), 73P/1930 J1 (Schwassmann–Wachmann), and C/1930 D1 (Peltier–Schwassmann–Wachmann). Comet 29P, in an unusually low-eccentricity orbit beyond Jupiter, is well known for its frequent, bright outbursts. 73P disintegrated almost entirely in 2006.

For more than four decades, Wachmann discovered and monitored the light fluctuations of variable stars, first photographically and then using photoelectric techniques. In 1939, he discovered the peculiar star, FU Orionis, a variable star that became a prototype of a subgroup of T Tauri stars that were young, low-mass stars with a slow but very large brightness rise. Now called FUORs, these stars are thought to experience occasional episodes of rapid accretion of material from disks surrounding them. In 1954, Wachmann published a monograph on FU Orionis. (He was a member of the Commission on Variable Stars of the International Astronomical Union.)

During his professional career, Wachmann discovered and observed several minor planets. One minor planet, (1704) Wachmann, honors his professional achievements.

Donald K. Yeomans

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Walcher of Malvern

Flourished **England, *circa* 1100**

Walcher was a prior at the abbey of Malvern. He produced an ecclesiastical (lunar) calendar, benchmarked to his observation of a lunar eclipse on 18 October 1092.

Selected Reference

Lindberg, David C. (1978). *Science in the Middle Ages*. Chicago: University of Chicago Press.

Waldmeier, Max

Born **Olten, Switzerland, 18 April 1912**
Died **Zürich, Switzerland, 26 September 2000**

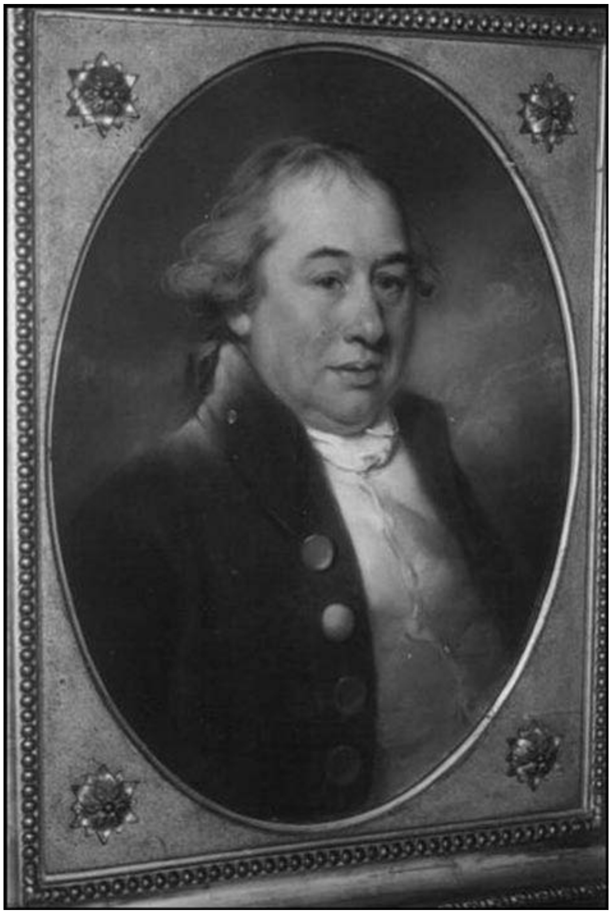
A custodian and compiler of **Johann Wolf**'s Zürich sunspot number, Swiss solar physicist Max Waldmeier created the nine sunspot classifications, A–J.

Selected Reference

Izenman, Alan Julian (1983). "J. R. Wolf and H. A. Wolfer: An Historical Note on the Zurich Sunspot Relative Numbers." *Journal of the Royal Statistical Society* 146: 311.

Wales, William

Born **Warmfield, Yorkshire, England, February 1734**
Died **London, England, 29 December 1798**



William Wales was an observational astronomer and teacher, best known for serving as one of the two astronomers on James Cook's second voyage to the South Seas. Born of humble parents, little is known of Wales's childhood except that he showed an early aptitude for mathematics. In 1765 he married Mary Green, youngest sister of **Charles Green** of the Royal Observatory, Greenwich, and was outlived by his wife and five of his children.

In 1766, Wales was commissioned by the Royal Observatory to carry out computations for the *Nautical Almanac* of 1767, and soon after was selected as one of the British observers for the 1769 transit of Venus expeditions. He and **Joseph Dymond** were forced to overwinter at the Prince of Wales's Fort in Hudson Bay, Canada, before successfully observing all four transit contacts on 3 June. They subsequently published their results in the *Philosophical Transactions of the Royal Society*. In common with other 18th-century observers, Wales and Dymond noted the contact-timing problems associated with the notorious "black drop" effect.

Following his Canadian escapade, Wales was appointed as astronomer on the *Resolution* for Cook's second voyage to the South Seas. His role was to make astronomical observations in order to determine latitude and longitude for navigational purposes, and equally importantly to monitor the accuracy of the Larcum Kendall K1 chronometer and one of the three chronometers manufactured by John Arnold. The K1 was a faithful copy of Harrison's famous prize-winning timekeeper. In addition to performing ongoing astronomical observations associated with navigation and timekeeping, Wales also observed solar and lunar eclipses and documented a number of aurorae, and together with William Bayly (astronomer on the second vessel, the *Adventure*) set about establishing the precise latitude and longitude of Queen Charlotte Sound, New Zealand, Cook's favorite Pacific revictualling center. After the voyage, Wales and Bayly wrote up their work, and *The Original Astronomical Observations. Made in the Course of a Voyage towards the South Pole …* was published in 1777.

But this did not end Wales's involvement with the Cook voyages, for in 1778 he was charged with producing the official astronomical account of the first voyage, a task fraught with difficulty given the death of the expedition's astronomer (his brother-in-law Green) on the voyage and the deplorable state of his papers. Compounding matters was the directive to include data from earlier South Sea voyages. As a result, *Astronomical Observations. Made in the Voyages which were Undertaken by Order of His Present Majesty, for Making Discoveries in the Southern Hemisphere …* only came off the press in 1788.

Part of the reason for the delay in preparing this volume lay in the fact that Wales was in full-time employment, for after returning from the South Seas in 1775 he had been appointed master of the Royal Mathematical School at Christ's Hospital in London. This novel academic institution was founded in 1673 in order to train budding ships' officers and others in the principles of mathematics and navigation. Over the years, Wales built the school into a great naval academy, and published two new editions of Robertson's *Elements of Navigation*, a book of his own on aspects of navigation (which also ran to two editions), and a volume on British demography.

In late 1776 Wales was elected a fellow of the Royal Society, a considerable honor at the time, and in 1795 he was appointed secretary of the Board of Longitude. By the time he died, he had made important contributions to 18th-century astronomy, navigation, and education. Professor **Thomas Hornsby**'s figure for the Astronomical Unit derived from Wales's 1769 transit of Venus observations and those of other British observers vary little from the currently adopted value. Wales's volumes on Cook voyage astronomy and on navigation are a testament to scholarship. His evaluation of the chronometers during the second voyage led eventually to their widespread adoption by the Royal Navy and through his post at Christ's Hospital a generation of boys learned the rudiments of mathematics and navigation.

Wayne Orchiston

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Walker, Arthur Geoffrey

Born **Watford, Hertfordshire, England, 17 July 1909**
Died **Sussex, England, 31 March 2001**

British mathematician Arthur Geoffrey Walker is remembered within cosmology for the formulation of the Robertson–Walker metric, a very general description of the four-dimensional structure of a homogeneous, isotropic space-time, applicable to the Universe as a whole.

Walker received an M.A. from Oxford University and a Ph.D. from the University of Edinburgh. He was appointed a lecturer in mathematics at Imperial College, London, in 1935, moved to Liverpool University (1936–1947) and to the chair of mathematics at the University of Sheffield, and finally returned to Liverpool University, from where he retired in 1974. Walker was a fellow of the Royal Society of London and of the Royal Society of Edinburgh, and received prizes from the Royal Society of Engineers and the London Mathematical Society.

Walker's research focused on geometry, especially Reimannian and other manifolds. In 1935/1936, he (and, independently, **Howard Robertson**) recognized that the solutions to **Albert Einstein**'s equations of general relativity, published earlier by **Wilhelm de Sitter** and **Georges Lemaître**, embodied a way of looking at the geometry of space-time that could be generalized to apply to a wider range of theories of gravity and cosmological models for any homogeneous, isotropic universe. The metric is still in general use, and a theory of gravity that cannot be put into metric form (this or some other) is automatically somewhat suspect.

Douglas Scott

Selected Reference

Walker, Arthur G. (1935). "On Reimannian Spaces with Spherical Symmetry about a Line, and the Conditions of Isotropy in General Relativity." *Quarterly Journal of Mathematics* 6: 81–93.

Walker, Sears Cook

Born **Wilmington, Massachusetts, USA, 28 March 1805**
Died **Cincinnati, Ohio, USA, 30 January 1853**

Sears Walker, a leading American mathematical astronomer, founded one of the first major research observatories in the United States and calculated a precise orbit for the newly discovered planet Neptune. He also headed the United States Coast Survey's pioneering development of longitude determinations using the telegraph, a technique that dominated geodesy worldwide in the 19th and into the early 20th century.

Walker was born near Boston, of farmers Benjamin Walker and Susanna Cook. As a child, his intellectual precocity and retentive memory were the wonder of the village and a worry to his mother, who tried to discourage his studiousness in favor of outdoor activity – to little avail; Walker was what today would be termed a workaholic, and was plagued by lifelong fragile health and obesity.

In 1825 Walker graduated from Harvard College, remarkably apt at acquiring languages and mastering Latin, Greek, Italian, and German. He taught school in Boston for 2 years before moving to Philadelphia, Pennsylvania (1827), his home for the next two decades. There Walker continued teaching for 8 years, spending his free time studying medicine, natural history, geology, mineralogy, physics, chemistry, and astronomy. One of his significant astronomical publications during this time was a set of tables (1834) for the parallax of the Moon that he had calculated for the latitude of Philadelphia, which reduced the time required for computing the phases of a lunar occultation to under half an hour. He also acquired a small Dollond refractor, a 20-in. focal-length transit instrument, and an astronomical clock, and began astronomical observations, eventually devoting all his leisure hours to astronomy alone.

In 1836, Walker gave up teaching to become an actuary for the Pennsylvania Company for the Insurance of Lives and Granting Annuities (a position analogous to that held by **Nathaniel Bowditch** in Boston around the same time), where he remained until 1845. In 1837, the Central High School in Philadelphia was founded, with $5,000 allocated to erect an astronomical observatory for the school. Walker, who in 1839 became the observatory's director, advised the founders to order the main instrument from Merz and Mahler in Munich, Bavaria, rather than from England or France. The 6-in. refractor (with a focal length of 8 ft.), installed in 1840, was one of the two largest telescopes in the United States from 1840 to 1843, and introduced the superior craftsmanship of the German makers to American astronomers. In the hands of Walker and his astronomer half brother E. Otis Kendall (who succeeded him as director), this high-school observatory became an acclaimed research institution, noted on both sides of the Atlantic for its comprehensive timings of lunar culminations and occultations for determining geographical longitudes and latitudes.

Although previously well-to-do, by 1845, unfortunate investments left Walker destitute at the age of 40. Fortunately, he was invited to join the US Naval Observatory, moving to Washington in 1846. That fall, the observatory's director **Matthew Maury** ordered Walker to calculate an orbit for the planet Neptune, recently discovered by **Johann Galle** in Berlin near the position for a hypothetical planet predicted almost simultaneously by **Urbain Le Verrier** of Paris and **John Adams** of Cambridge University. In early 1847, Walker discovered that on 8 and 10 May 1795, Neptune had been observed as a fixed star by **Joseph de Lalande**, director of the Paris Observatory, and had been so recorded in Lalande's 1802 catalog of 47,000 stars, *Historie céleste française*. From that additional position, Walker was able (in part based on gravitational perturbations calculated by Harvard mathematician **Benjamin Peirce**) to calculate an orbit for Neptune that accurately predicted the planet's future positions – an achievement that won him international renown.

Meanwhile, unhappy under Maury, Walker left the Naval Observatory and was promptly hired by **Alexander Bache**, superintendent of the Coast Survey, the agency charged with accurately charting all US shorelines. There, Walker took charge of determining longitudes by the new technology of the telegraph, a position he held until his death.

Because of the rotation of the Earth, a difference in longitude is equivalent to a difference in local time (as measured by the stars). But there was no direct way to compare clocks that were hundreds of miles apart – until 1844, with the advent of the telegraph and its seemingly instantaneous signal-transmission time. As soon as telegraph lines reached a city, Walker traveled to local observatories to determine longitude differences between them and other key points, rapidly tying into one geodetic system points ranging from Charleston, South Carolina, to Cincinnati, Ohio, to Halifax, Nova Scotia, Canada. The telegraphic method of determining longitudes – soon dubbed the American method – became standard in geodesy until displaced by radio techniques in the 1920s.

By pure serendipity, Walker's work with the American method led to a crucial scientific observation. In January 1849, during the first experiment with permanently recording the local times of star transits over four observatories of differing longitudes, Walker noticed that the transit times recorded at each observatory compared with the time signals from one central clock differed depending on the distance of the observatory from the recording apparatus. In short, he stumbled onto the discovery that an electromagnetic signal was not instantaneous (the accepted view) but had a finite and measurable velocity through the circuit of about a tenth the speed of light in a vacuum.

In August 1851 Walker was afflicted by mild paralysis that deprived him of the use of one hand for several days. Despite pleas from friends and physician, he kept his usual schedule of working dawn to dusk. In 1852, showing symptoms of mental illness, he spent several months recuperating at two asylums, even there still working ceaselessly to refine the ephemeris of Neptune. During a visit to his brother Timothy, the never-married Walker died from fever.

Trudy E. Bell

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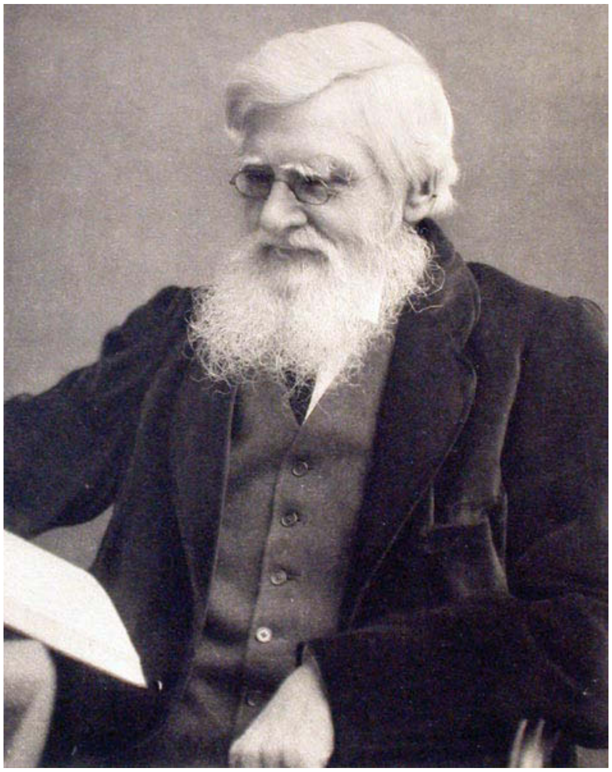
Wallace, Alfred Russel

Born **Usk, Monmouthshire, Wales, 8 January 1823**
Died **Wimborne near Bournemouth, Dorset, England, 7 November 1913**



Although Alfred Russel Wallace made significant contributions to astronomy, he is best known as a central figure in the emergence of the fields of evolutionary biology and biogeography.

As the eighth of nine children of Thomas Vere and Mary Anne (*née* Greenell) Wallace, poor but middle-class English parents, Alfred Wallace led a rather ordinary life until his midteens. At that time, while working as a surveyor in western England and Wales, he began to take an amateur's interest in natural history. In the early 1840s Wallace became involved in local mechanics' institutes as a lecturer, curator, and possibly librarian. In 1844 he took a position as a master at Leicester School, where he incidentally met another famous naturalist-to-be, Henry Walter Bates. The two would eventually decide to turn professional as natural history collectors. In 1848 they voyaged to the Amazon region, where in the following years they were quite successful collecting specimens. Wallace returned to England in 1852 when his health deteriorated; on the way he narrowly escaped death when his ship caught fire and sank, but he lost some 2 years of collections in the disaster. Undaunted, Wallace set off for the Far East 18 months later to reimmerse himself in collecting activities.

Wallace's name is now inextricably linked with the Malay Archipelago, where 8 years of fieldwork (1854–1862) secured for him a reputation among future generations as history's greatest tropical naturalist. While there he thought out the theory of natural selection; the famous essay on the subject he sent to Charles Darwin is now well known to have propelled the latter into finally committing his own ideas to paper in *On the Origin of Species* in 1859. Over the same period Wallace made fundamental contributions to the study of biotic distribution patterns, and is now regarded as the father of the science of zoogeography. Wallace returned to England in 1862, thereafter settling down to a long career of study and writing.

Wallace's contributions to astronomy are overshadowed by his fame in other natural sciences, but his thoughts and writings on astronomical topics were and still are influential, and in some areas he may be regarded as an important pioneer. Although lacking even a secondary-school education, he developed a firm grasp of basic scientific principles, and later was particularly brilliant at marshaling evidence and drawing conclusions. Wallace's attention was drawn to astronomy during his early surveying days, when practical geodetical matters were of daily concern. He developed a talent for cartography, a skill he would exercise during his Amazon travels by producing one of the first reliable maps of the course of the Rio Negro.

In 1865, after his return from the Malay Archipelago, Wallace became embroiled in a public discussion on the shape of the Earth. While discussing this incident in his 1905 autobiography *My Life* he produced a nontechnical explanation of the derivation of latitude that geographer Yi Fu Tuan would later describe as never having been surpassed in clarity. Wallace's fascination with geodesy culminated in 1870 when he devised the celebrated Bedford Canal experiment, an attempt to silence the claims of a particularly outspoken advocate of a flat Earth.

In the 1860s Wallace also became interested in **James Croll**'s ideas about the possible astronomical causes of the glacial epochs. Wallace adopted some of Croll's theory of climate change as related to eccentricity of the Earth's orbit and precessional movement of its axis, but added his own twist by examining possible synergistic interplays between astronomical and climato–geographical forces. His fully developed theory along these lines – the first of its kind – was presented as the opening sections of the book *Island Life* in 1880.

In 1896 Wallace was invited to Switzerland to give a lecture on scientific progress; the research he did for this lecture and in 1898 for a related book, *The Wonderful Century*, rekindled his interest in astronomy, and he soon took up the subject again. Adopting **William Whewell**'s position on the plurality of worlds and relying on his thorough review of the recent astronomical literature, Wallace attempted to make the argument that the Earth and Solar System are located at the very center of the Universe. Further, he argued that, on a consideration of the physical improbabilities involved, ours is probably the only existing world inhabited by advanced creatures. This position was first advanced by Wallace in an essay published in early 1903, but later that year he produced a much-expanded discussion in the book *Man's Place in the Universe*, which drew both much attention and much criticism.

A few years later Wallace was drawn into the discussion surrounding **Percival Lowell**'s sensational view that the planet Mars is inhabited by advanced beings. In 1907 Wallace published a short book, *Is Mars Habitable?* that devastatingly criticized the range of problems inherent in Lowell's position. The discussion remained close to principles of basic science with Wallace surmising that the Red Planet's surface must be desertlike and devoid of higher life forms. He was able to accurately deduce its likely surface temperatures and albedo, and to suggest that its polar caps are probably frozen carbon dioxide rather than frozen water.

The astronomical writings Wallace produced over the last decade of his life reflect an unusually flexible worldview: one scientific enough to address questions bearing on proximate causalities, yet philosophical enough to find a place for final causes. Although he has sometimes been accused of theistic leanings, he strictly rejected the notion of a reality operating on first causes and therefore, in spite of all his spiritualist beliefs, was in no sense a creationist. Still, he did believe there was purpose exhibited by natural structure and its programs of change. In examining this matter scientifically in the context of astronomy Wallace became perhaps the first important purveyor of what has come to be known as the anthropic principle. With this philosophical perspective it is all the more interesting that his most important contribution to the progress of astronomy was a methodological one: his analytical approach to the study of planetary atmospheres and surfaces toward the end of assessing their potential for life-sponsoring conditions. For this latter work he may justly be regarded as a founding father of the science of astrobiology.

Wallace's career, especially after 1862, was characterized by frequent public controversy, for in addition to his natural science interests Wallace was also a vocal and demonstrative spiritualist, land nationalizer, antivaccinationist, and socialist. In April 1866 at the age of 43, he married Ann Mitten, the 20-year-old daughter of the English botanist William Mitten. They had three children, two of whom survived to adulthood. By the time of his death, Wallace was well honored: He was a fellow of the Royal Society and received the society's Royal Medal (1868), its Darwin Medal (1890), and its Copley Medal (1908). Among many other honors including two honorary doctorates, he was the first recipient of the Darwin–Wallace Medal of the Linnean Society of London (1908) and the Order of the British Empire.

Charles H. Smith

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Wallis, John

Born **Ashford, Kent, England, 23 November 1616**
Died **Oxford, England, 28 October 1703**

Aristarchus expert John Wallis was primarily a mathematician, and should be considered one of the inventors of analytic geometry. He lived during the English Revolution, and Oxford fell into the portion of England that sided with the Parliamentarians. Wallis decoded some messages from Royalists that came into the hands of the Parliamentarians. He was later accused of having decoded the personal letters of King Charles himself, a charge that Wallis adamantly denied. In his old age, Wallis taught what he knew of cryptography to his grandson, William Blencowe, though by then, Wallis admitted, the new French methods of encryption were too complicated to break by the means used by Wallis.

In 1649, Wallis became Savilian Professor of Geometry at Oxford, more likely because of his support for the Parliamentarians than for his mathematical ability. However, he soon proved that, political appointment or not, he well deserved the chair. In 1663, he was elected a fellow of the Royal Society.

Through the use of conjecture and interpolation, he was able to obtain an infinite product expansion for π, and had a considerable influence on **Isaac Newton**'s mathematical development. Wallis also played an important role in the development of analytic geometry and was among the first to consider curves defined purely by an algebraic equation.

Wallis's main contribution to astronomy was his publication and annotation of the Greek text *On the Sizes and Distances of the Sun and Moon* by Aristarchus. Aristarchus was the first to put forward a heliocentric model of the planetary system, and **Nicolaus Copernicus** used Aristarchus's work to support his own. Latin and Arabic translations of Aristarchus's writings were widely available, but Wallis's 1688 version was the first printed edition of the Greek text. Wallis based his work on two copies, one made by **Henry Savile** from a copy in the Vatican, and the second a Greek manuscript in the possession of Edward Bernard, the Savilian Professor of Astronomy at Oxford.

Jeff Suzuki

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Walther, Bernard [Bernhard]

Born **Memmingen, (Bavaria, Germany), 1430**
Died **Nuremberg, (Germany), 15 June 1504**

Bernard Walther was, after the death of **Johann Müller** (Regiomontanus), the leading astronomer of his time. Though unpublished in his lifetime, Walther's 30-year series of astronomical observations established a new approach to observational astronomy based on the integrity of the instrument with due concerns for accuracy, and awareness and recording of conditions attendant to observations. Walther's observations were later used to advantage by **Nicolaus Copernicus**,

Johannes Kepler, and **Tycho Brahe**, and for the first time demonstrated the value of an extended series of observations for testing theories.

Walther was a Nuremberg merchant who may have helped to fund the observing program of Regiomontanus. Though such patronage has not been proven, Walther proclaimed he was a student of Regiomontanus. Walther and Regiomontanus often observed together. Like Regiomontanus before him, Walther noted discrepancies for the positions of the planets and circumstances of eclipses published in Regiomantanus' almanacs, which were based on the *Alfonsine Tables*. The understanding of these important discrepancies and improvement of astronomical tables became the rationale for their observing program of planetary positions and eclipse timings.

Walther carried on the procedures of astronomical observation after the death of his teacher. He safeguarded much of Regiomontanus' estate, preserving for eventual publication many manuscripts involving both astronomical data and theory. Strangely though, Walther published neither manuscripts from Regiomontanus nor his own data. He apparently withheld the observations and manuscripts that he had inherited from other astronomers during his own lifetime.

Walther modified his Nuremberg house so that he could make nighttime observations of the sky. The Walther residence was evidently Nuremberg's first astronomical observatory. The famous artist **Albrecht Dürer** later occupied the house; it remained standing until it was destroyed in World War II.

After Regiomontanus's death, Walther bought his mentor's brass observing instruments, and continued to make many astronomical observations. These instruments included a mechanical clock, an armillary sphere, and astrolabes.

Regiomontanus suggested using a geared clock for timing astronomical events. This suggestion spurred Walther to use such a clock in some of his astronomical observations beginning in 1484. Though clocks at that time were not very reliable, and he evidently did not use one all the time, Walther is one of the first astronomers to do so, though his use of a clock was possibly preceded by John Abramius several decades earlier. An analysis of the timings of six different eclipses by Walther and Regiomontanus has shown that they attained an accuracy of about 7″.

Another Walther contribution to improved observing practice was that he recorded sky conditions and estimated the reliability of each astronomical observation. Walther's example set a precedent that would be followed in the 16th century by others who read his notes after they were published with the observations in 1544 by **Johannes Schöner**.

Walther's positional observations were unusually accurate. His long series of many hundreds of observations of the Sun, planets, and at least one comet made an impact on later observers and analysts of astronomical data. For example, Schöner evidently obtained the papers of Walther and Regiomontanus sometime after Walther's death and may have provided them to Copernicus who used some of Walther's observations in his *De revolutionibus*. In discussing the Moon's motion in his 1604 *Optical Part of Astronomy*, Kepler used the example of Walther's 1482 observation of a lunar occultation of Saturn. Brahe also alluded to Walther often, and used his data to evaluate atmospheric refraction as well as competing theories of solar motion. Walther was a careful enough observer that he discovered atmospheric refraction for objects low in the sky before learning in astronomy treatises that earlier observers also had done so.

Little else is known about Walther, other than that he was part of a circle of humanists in Nuremberg and that he knew Greek. A surviving will indicates that he was a man of modest means.

Daniel W. E. Green and *Thomas R. Williams*

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Wang Xun

Born **(Hebei), China, 1235**
Died **China, 1281**

Wang Xun was a Chinese mathematician and astronomer in the Yuan dynasty (1260–1367). He learned to read at 6 years of age and became interested in mathematics and nature. Wang Xun went to Zijing Mountain in Hebei to study with Liu Bingzhong (1216–1274), a well-known scholar in the Yuan dynasty. At the same time, **Guo Shoujing** (1231–1316) was also one of Liu's students. Under the guidance of Liu, Wang Xun devoted himself to the study of mathematics and astronomy, which laid the foundation for his future astronomical research. After finishing his study at Zijing Mountain, Wang Xun was recommended by his teacher to Khublai Khan (1215–1294) and was appointed tutor to the crown prince. In 1261/1262 he was promoted twice to higher office. Meanwhile, he became a well-known mathematician.

In 1276, acting on the earlier advice of Liu Bingzhong, Khublai Khan decided to reform the calendar after the existing calendar was found to be inaccurate. He set up a new astronomical and historiographical bureau, the Taishiju, to undertake the work. Wang Xun was appointed supervisor of the academic activities in the bureau; Guo Shoujing was also transferred there from the water conservancy department. The Taishiju developed into the Taishiyuan, the Imperial Bureau of Astronomy and Calendrics (1279). Wang Xun therefore was promoted to Taishiling, the highest academic post in the bureau, and Guo Shoujing became his deputy. Of course, there were other higher officials, such as **Xu Heng**, who were in charge of the administration of the institute.

To fulfill the task of calendrical reform, an observatory was established in the capital, Dadu (the present Beijing), and several new astronomical instruments were designed and built. Meanwhile, a large-scale research program was initiated. The program consisted of astronomical observation, nationwide surveying of the altitude of the North Celestial Pole (equivalent to geographical latitudes), measurement of gnomon-shadow lengths at the summer solstice, studies of the history of calendars, and a great deal of calculation. Several scholars took part in the program, sharing the work and cooperating with one another. Wang Xun took on the task of the calculations, Guo Shoujing designed and made instruments and astronomical observations, Xu Heng studied the history of astronomy, and Duan Zhen constructed the observatory. The result of the program was the completion of a new calendar in 1281 called the Shoushi Calendar.

As a mathematician, astronomer, and supervisor-general of the whole program, Wang Xun made a significant contribution to the development of the Chinese calendar and astronomy. Worn out from constant overwork and the death of his family members, Wang died.

Guo Shirong

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Ward, Isaac W.

Born **Belfast, (Northern, Ireland), 13 September 1834**
Died **Drumbeg, (Northern, Ireland), 11 October 1916**

Belfast amateur Isaac Ward spied a “new” star on 19 August 1885. This object, appearing in the Great Andromeda Nebula (M31), was the first recorded extragalactic supernova (SN 1885A). The following evening it was also observed by **Ernst Hartwig**.

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Ward, Seth

Born **Aspenden, Hertfordshire, England, April 1617**
Died **London, England, 6 January 1689**

Seth Ward was a mathematician, astronomer, clergyman, and controversialist. Baptized on 5 April 1617, he was the second son of John Ward, an attorney, and Martha (*née* Dalton) Ward, mother of six. After taking degrees at Cambridge (BA: 1637; MA: 1640) Ward was appointed Savilian Chair in Astronomy at Oxford (1649–1661), having been nominated by his ousted predecessor, **John Greaves**. Previous Savilian professors—**John Bainbridge** and Greaves—taught **Ptolemy**; Ward was the first to lecture on the Copernican Systems. A founding fellow of the Royal Society, Ward produced several short works in mathematics before becoming Bishop of Exeter (1662) and Salisbury (1667). When Ward finally left Oxford and academic life (1662), the Savilian Chair was taken by **Christopher Wren**.

Ward’s career in science was marked by controversy. The first dispute, now known as the Webster–Ward debate, focused on the role of the New Science in the university curriculum. In his *Vindiciae academiarum* (Oxford, 1654), Ward opposed claims of John Webster and positions taken by Thomas Hobbes, arguing that the mathematical sciences were faring well in England and that university reform was unnecessary. Ward later attacked Hobbes’ materialist philosophy in his *Thomae Hobbii philosophiam exercitatio epistolica* (Oxford, 1656).

But Ward’s defining contribution to astronomy – the so called “simple elliptical hypothesis” – emerged from the Boulliau–Ward debate. This dispute focused on Kepler’s laws, or more precisely, alternatives to **Johannes Kepler**’s first two planetary rules, now known as the ellipse and area laws. Significantly, deep cosmological concerns formed the core of the debate, issues first framed by **Ismaël Boulliau** in his influential *Astronomia philolaïca* (Paris, 1645). Here Boulliau made startling claims against Kepler’s now-famous cosmological contributions. Calling Kepler “ingenious” and “sagacious,” as well as a “mediocre geometer,” Boulliau rejected Kepler’s celestial physics as “mere figments” and dismissed his demonstrations as “a-geometric.” In place of Kepler’s *anima mortrix* and “magnetic fibers” Boulliau argued it was more natural to assume that the planets were self-moved. In place of Kepler’s cumbersome geometry (involving trial and error approximation) Boulliau proposed a “direct solution” based on mean motion.

Here Ward opposed Boulliau’s assumptions, methods, and conclusions. Prompted by Sir Paul Neile, Ward published two treatises attacking Boulliau’s geometrical procedures. In his *Inquisitio brevis* (1653) Ward claimed to produce a more accurate elliptical theory, the “simple elliptical hypothesis,” which had in fact been known earlier to Kepler, **Albert Curtz**, and Boulliau himself. Focusing strictly on mathematical methods, Ward never questioned the empirical accuracy of Boulliau’s theory but insisted (incorrectly) that his results were more accurate. Three years later Ward published his *Astronomia geometrica* (1656), which provided a more polished account but which continued to ignore empirical factors. Finally, in the following year, Boulliau responded with his *Astronomia philolaica fundamenta clarius explicata* (Paris, 1657). After acknowledging his error (noted in his *Astronomia philolaïca*), Boulliau demonstrated that Ward had mistakenly identified the conical hypothesis with his alternative "simple elliptical" model, that is, an ellipse where the empty (non-solar) focus served as an equant point. To demonstrate the difference, Boulliau cleverly argued that if Ward's hypothesis were applied empirically to the planet Mars, it would result in a maximum error of over 7′ in heliocentric longitude – not the 2.5′ calculated from the conical hypothesis. While his "modified elliptical hypothesis" (1657) seemed to win the day – it surpassed the accuracy of Kepler's "area law" for Mars – Boulliau's cosmological principles failed to excite focused attention.

But the technical debate continued. Over the next three decades the great debate on the "problem of the planets" was largely reduced to quibbles about "saving the appearances." But there was wide agreement about planetary orbits. By the 1660s the elliptical path was commonplace. Thanks to Boulliau's "English Lieutenants" (**Jamy Shakerley,** John Newton, **Vincent Wing**, **Nicolaus Kauffman** (Mercator), and **Thomas Streete**), the modified elliptical hypothesis had been continually refined. Yet in retrospect this technical success was also marked by failure. Debates of the 1660s and 1670s failed to illuminate the critical relationship between computational simplicity and cosmological explanation. If this lapse marks a "retrograde step," it was not a singular *faux pas*. In any case, by the 1670s the "problem of the planets" had became an English affair, and by tradition, that decade marks the uneasy divide between "post-Keplerian" and "pre-Newtonian" astronomy. In the end, by the time of **Isaac Newton**'s *Principia* (1686), Ward had left a large legacy of sermons but nothing new in science. Most of Ward's papers are lost – reportedly his cook used them for kindling and as doilies for cooling potpies.

Robert Alan Hatch

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Wargentin, Pehr Wilhelm

Born **Sunne Prästgard, Sweden, 11 September 1717**
Died **Stockholm, Sweden, 13 December 1783**

Pehr Wargentin, secretary general of the Royal Swedish Academy of Sciences from 1749 to 1783, was a renowned Swedish astronomer and statistician who devoted much of his scientific energy to the study of the motion of Jupiter's satellites. Pehr was the son of Wilhelm Wargentin, vicar of Sunne Parish, and Christina Aroselius. He married Christina Magdalena Raan in 1756. Together, they had three daughters and remained together until Christina's death in 1769.

Wargentin became interested in astronomy as a youth and, after receiving his early education at Frösö Trivialskola, he began his studies at Uppsala University on 30 January 1735. There he was introduced to professor **Anders Celcius**, who led Wargentin to become interested in the study of the motion of Jupiter's satellites. On 12 December 1741, Wargentin defended his dissertation entitled *De satillitibus Iovis*, a treatise on the history and motions of these satellites and developed *Tabulae pro eclipsibus satellitym Iovis*, a table for finding the known moons of Jupiter, which caught the attention of the academic world. In 1746 he presented the dissertation *De incremento astronomiae ab ineunte hoc seculo* and was appointed to the position of senior lecturer at the university. Wargentin was elected to the Swedish Academy of Sciences in 1748 and was appointed to the philosophy faculty at Uppsala University in the same year.

In 1753 Wargentin became the first director of the Stockholm Observatory and arrived there on 12 April. The observatory opened on 20 September 1753, and again he devoted his time to studies of the motion of Jupiter's satellites. His continued interest in this area is understandable, because one of the most important problems of the day was the development of a method for determining the "longitude of places," particularly for shipboard navigation. At that time there was considerable support for using the motions of the Jovian moons as a means of determining time for conversion to a measure of terrestrial longitude. In addition, Wargentin's studies also included observations of the opposition of Mars in 1751 and observing the transits of Venus in the 1760s when it twice passed between the Earth and the Sun. The quality of his work was well recognized and resulted in his election to fellow of the Royal Society in 1764 as well as his becoming a member of the French Academy of Sciences.

Wargentin's contributions to science went beyond astronomy. He held the position of secretary general of the Royal Swedish Academy of Sciences for more than 30 years, and he headed the government agency Tabellverket, which was established to compile population records and was the forerunner of Statistics Sweden. The collection of population records in Sweden had its beginnings with a 1686 law that required the Church of Sweden to keep records of people who moved in and out of each parish. Through Wargentin's efforts in compiling these records he is considered to have laid the groundwork for modern Swedish population statistics.

Scott W. Teare and *M. Colleen Gino*

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Wassenius [Vassenius], Birger

Born **Mankärr near Vänersborg, Sweden, 26 September 1687**
Died **Mankärr near Vänersborg, Sweden, 11 January 1771**

Birger Wassenius is best known for his early descriptions of solar prominences and earthshine. Wassenius's father, Jonas Wassenius, was yeoman of the guard under Carl XI, and his mother was Märta Torstendotter. Meager family means kept him in Vänersborg schools until 1712, when he began studying mathematics, physics, and astronomy in Uppsala, obtaining a philosophy degree in 1722. While a student Wassenius made a living by regularly journeying to the countryside to tutor students, and he is said to have built his own astronomical instruments out of wood and moose antlers. Wassenius married Ebba Regina Spalk, and from 1735 onward, under the patronage of Göteborg Bishop Erik Benzelius, he held lectureship positions at the gymnasium in Göteborg. In 1751 he retired to Mankärr.

Wassenius's claim to astronomical fame rests primarily on his description of solar prominences and earthshine, both of which he noted while observing the total solar eclipse of 13 May 1733 from the vicinity of Göteborg. Wassenius's writings represent one of the earliest, unambiguous descriptions of solar prominences. He also first noted the existence of earthshine, the faint illumination of the lunar disk at totality due to sunlight reflected from Earth. Wassenius suggested that prominences were clouds in the Moon's atmosphere, an idea that was convincingly refuted only much later, via sequences of photographs taken by **Warren de la Rue** and **Angelo Secchi** at the 18 July 1860 eclipse, in Spain. Wassenius also wrote yearly almanacs from 1724 to 1748, and had a lifelong interest in geophysical phenomena.

Paul Charbonneau

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Waterston, John James

Born **Edinburgh, Scotland, 1811**
Died **Edinburgh, Scotland, 18 June 1883**

John Waterston, a technically trained and competent amateur Victorian scientist, was a pioneer (with John Herapath) of the kinetic theory of gases and, along with **Julius Mayer**, one of the pre-discover of the Kelvin-Helmholtz theory of solar energy. His grandfather, William Waterston, was the founder of a successful business for the manufacture of sealing wax, while his grandmother, Catherine (*née* Sandeman, of the well-known port wine merchants) was within a line of religious intellectuals known as Glasites or Sandemanians, a Scottish sect that valued independence of thought and which included Michael Faraday among its active followers. John, the sixth of the nine children of George Waterston and Jane Blair, had a privileged childhood in a culturally rich and emotionally happy family, which valued education and intellectual achievement. Several of his family contemporaries were successful as military men, bankers, and merchants.

After attending the Edinburgh High School, a leading school in Scotland, Waterston became apprenticed to a civil engineering firm, while attending the University of Edinburgh. He studied mathematics and physics with Sir John Leslie, famous as a mathematician and physicist interested in the heat absorption and reflection properties of various materials. Leslie trained a series of distinguished scientists. In 1832 Waterston moved to London, to the firm of James Walker, a leading civil engineer and president of the Institution of Civil Engineers. After 3 further years in engineering, Waterston sought employment that might provide him the leisure and time to follow his scientific interests, and took a post in the Hydrography Department of the Admiralty. This course of action was prompted by his family's belief that one should separate one's main interests in life from the means by which one earned a living. In 1839 he obtained a post at a substantial salary as naval instructor at the Bombay Academy of the East India Company. Although he had published a scientific paper before leaving Edinburgh (an attempt at a mechanical explanation of gravity with obvious connections to his later work on the kinetic theory of gases), his main scientific work, which encompassed biology and psychology as well as physics and astronomy, was accomplished in India.

Navigation and gun laying were Waterston's instructional responsibilities with the naval cadets, so his interests extended into astronomy as well as physiology, physics, and chemistry. His papers on astronomical topics, starting in 1842, included a navigational discourse on how to find the latitude, time, and azimuth at a given position; an interesting simple graphical method of predicting lunar occultations; several papers on comets (in one of which Waterston came very close to describing the effect of solar wind on cometary tail formation and morphology); and an interesting treatise on observations of solar radiation. Most of these papers were communicated to the Royal Astronomical Society [RAS] in London and printed in their *Monthly Notices*. In 1852, Waterston became a life member of the RAS.

Waterston had become interested in the kinetic theory of gases after trying to calculate the age of the Sun. He realized that chemical processes were insufficient to account for the energy released by the Sun, and postulated that kinetic energy released by the impact of meteors was a possible source of the needed additional energy. Waterston wrote two notes, and then a full paper, setting out his ideas on a kinetic theory of gases. In the paper, Waterston laid out an elaboration on his theory that heat in a gas was a function of the *vis viva* or kinetic energy of the molecules in the gas. His statistical approach included the concept of mean free path and other details that anticipated the work of Rudolf Clausius and **James Maxwell** by about 20 years. He showed how the empirical laws of Boyle and Charles could be derived theoretically from kinetic theory, and that through it, the laws of Avogadro and of Dulong and Petit, would follow directly.

In 1845, Waterston's paper was communicated to the Royal Society in London, where it was read but rejected for publication by the society's referees. As was the practice, Waterston's manuscript was not returned to him, but instead became the property of the Royal Society and was retained in the archives. Waterston had not made a copy of this complex manuscript and was unable to reconstruct it in sufficient detail to submit it for publication elsewhere. By the time he realized it would not be published by the Royal Society, his interest had passed on to the physical chemistry of liquids and gases. Although Waterston later referred to his paper on the kinetic theory of gases several times in oral presentations and other publications, especially one on acoustics and the speed of sound, he never published the ideas presented in this seminal paper.

Waterston returned to Scotland from India in 1857, apparently in frustration over his problems with getting his other scientific work published. In Edinburgh, later in Inverness, and then again in Edinburgh, he continued work that was essentially in physical chemistry, working on the properties of gases and liquids at their interface and exploring the properties of the triple point, surface tension, and capillarity. During his time in India Waterston had suffered a heatstroke while making measurements of solar radiant energy, and was thereafter subject to periodic spells of disequilibrium and dizziness. It is likely that such a spell accounted for his mysterious disappearance during a walk along the Edinburgh waterfront; authorities at the time assumed he fell in the water and drowned, although his body was never found.

While working on acoustics, Lord Rayleigh found Waterston's manuscript in 1891, and recognized its importance in the light of the later theories of Maxwell and Clausius. He immediately had Waterston's manuscript published in the *Transactions of the Royal Society*. In his introduction to the paper, Lord Rayleigh commented that Waterston's paper represented "… an immense advance in the direction of the now generally received theory. The omission to publish it at the time was a misfortune which probably retarded the development of the subject by ten or fifteen years." The original rejection of Waterston's paper may be understood in the context of the prevailing theories of heat, despite the fact that he had previously published papers in the RAS *Monthly Notices*. In mitigation of the Royal Society decision, Lord Rayleigh and others have pointed out that the referees were acting in good faith and on their best understanding of the state of the science at the time, and had acted properly, though unfortunately, in the matter.

David Jefferies

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Watson, James Craig

Born **near Fingal, (Ontario, Canada), 28 January 1838**
Died **Madison, Wisconsin, USA, 22 November 1880**

As a professor and observatory director at the universities of Michigan and Wisconsin, James Watson was an important figure in 19th-century American astronomy. His astronomical career was largely dedicated to visual observations and orbit calculations of solar-system objects. He discovered 22 asteroids, but his search for the hypothetical intra-Mercurial planet Vulcan proved fruitless.

Watson was the eldest son of William Watson, a farmer, schoolmaster, and factory worker, and Rebecca (*née* Bacon) Watson. William's father was one of the original settlers in 1811 in the region of colonial Canada where James was born and raised. Though James's grandfather prospered, his father struggled to support his wife and four children. Hoping for better prospects in the United States, the family moved to Michigan in 1850, but in fact James had to work with his father in various menial jobs and in a factory. The mechanical skills he picked up there proved valuable later in his career. He learned mathematics, Greek, and Latin mainly on his own and in his spare time. This helped him gain admission to the University of Michigan at the young age of 15. Watson was a precocious youngster who seemed to master any subject that he encountered.

The circumstances that led Watson to astronomy were fortuitous. In 1852 the University of Michigan at Ann Arbor appointed its first president, Henry Philip Tappan. Determined that science should be prominent in the curriculum, Tappan wanted an observatory to be part of the university. With the financial backing of generous donors in Detroit, he was able to make his dream in that regard a reality. In 1853, as Watson was beginning his studies at the university, Tappan was in Germany finding out firsthand about the education system there and how best to equip an observatory. At Berlin, Tappan met the famed astronomer **Johann Encke** and his assistant **Franz Brünnow**. On their advice, Tappan ordered a Pistor & Martins meridian circle and clock made by Tiede, which were installed in Ann Arbor the following year. A Fitz 13.6-in. refractor was put into service in 1857. Watson was to use these instruments to great advantage in the years ahead. Tappan recruited Brünnow himself to be the first director of the observatory. Few students were able to benefit from Brünnow's demanding courses in spherical and practical astronomy, but those that did became his intellectual descendants forming what has been called the Ann Arbor School of Astronomy. Watson was foremost among them.

Even before Watson received his A.B. degree in 1857 his first scientific contribution was published – the elements of comet C/1857 D1 (d'Arrest). It was his first of over 60 papers giving either elements or observations of comets or asteroids. His command of celestial mechanics and his great facility in rapid computation made him a natural for this sort of work. While pursuing his master's degree, Watson assisted in the observatory of the University of Michigan and in 1859 took charge of it while Brünnow was away for a year as interim director of the Dudley Observatory in Albany, New York. On Brünnow's return in 1860, Watson was assigned to the chair of physics and was temporarily diverted from observing. That year he wrote a popular book on comets, married Annette Waite, and began extramural work reducing observations for **Benjamin Gould**.

When, at age 25, Watson became professor of astronomy and director of the observatory following Brünnow's resignation, he began his astronomical career in earnest, lecturing, computing, observing, and discovering the first of his 22 asteroids. His prolific success in this field earned him many honors. Nowadays Watson is more likely to be remembered for his textbook *Theoretical Astronomy* published in 1868 and reprinted as recently as 1981.

Watson was elected to the National Academy of Sciences [NAS] in 1868, and under their auspices in 1874/1875 he and his wife made a round-the-world trip culminating in the successful observation of the transit of Venus in China. The NAS appointed Watson to three solar-eclipse expeditions, one to Iowa in 1869, another to Sicily the following year, and the last to Wyoming in 1878.

It was on the latter occasion, during totality, that Watson was convinced that he had discovered two planets close to the Sun. The actual discovery of an intra-Mercurial planet would not only have made Watson a celebrity but would have been seen as a triumphant vindication of **Urbain Le Verrier**'s theoretical proposal of 1859 that such a planet could explain the anomalous advance of Mercury's perihelion. As it turned out, his observations (and similar though discordant ones by **Lewis Swift**) were never explained. The phenomenon that Le Verrier sought to explain was eventually accounted for in 1915 by **Albert Einstein** in his theory of general relativity. Watson, however, was always convinced of the legitimacy of his observations and hoped to confirm his work. This quest was a factor in his decision to accept a position as director of the new Washburn Observatory in Madison, Wisconsin.

Attracted by the promise of better equipment, Watson and his wife and mother moved to Madison in 1879. Much of the design and supervision of the observatory's construction fell on his shoulders. At his own expense, he also began work on an underground solar telescope, which, by means of a heliostat, would allow him to search for planets very close to the Sun. All these responsibilities took their toll, and Watson died of intestinal inflammation, leaving his widow and no children.

Watson's hardship in his early years affected him throughout his life. He seemed to be continually seeking financial opportunities beyond the observatory. He was an insurance agent, and later an actuary; he was in the stationery business, selling photos and books, and he became president of the Ann Arbor Printing and Publishing Company. Consequently, even though he died young, Watson left a considerable estate. Most of it, over $18,000, went to the NAS to continue work on the asteroids he had discovered; **Simon Newcomb** was among his executors. The fact that Watson was brilliant and that he learned and earned a great deal without outside help made him ambitious and confident. Except for Vulcan, his achievements were genuine and were recognized by his colleagues at home and abroad with honorary degrees and awards, including the Lalande Prize in 1870.

Watson's papers are found mostly in the University of Michigan Archives, Bentley Historical Library, Ann Arbor; in the Archives of the Department of Astronomy, University of Wisconsin; and in the Library of the Wisconsin Historical Society, Madison.

Peter Broughton

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Watts, Chester Burleigh

Born **Winchester, Indiana, USA, 27 October 1889**
Died **Annandale, Virginia, USA, 17 July 1971**

Chester Watts contributed important scientific and technological improvements to meridian astrometry and to our knowledge of the topography of the Moon in the marginal or libration zones.

Watts was born to Joseph and Ada (*née* Irey) Watts. His father was a railway postal clerk while his mother was, for a short time, a schoolteacher. Watts became interested in astronomy at an early age and constructed a working sextant with which he took his first astronomical measurements. From July 1911 to September 1914 he worked at the United States Naval Observatory [USNO] as a miscellaneous computer, returning to Indiana to marry Ada Williams and complete his BA degree with distinction in astronomy at Indiana University in 1915. Watts then resumed his employment at the USNO and spent his entire career there. For the first 4 years he worked in the USNO Time Service Division. In 1919 he was transferred to the Six-Inch Transit Circle Division and was appointed director of that division in 1934.

His imaginative abilities with machinery and creative approach to experimentation led Watts into a remarkable career in observational astronomy. He brought marked improvements to the USNO's Six-Inch Transit Circle, including automation of the traveling thread micrometer and photographic recording of the circle and micrometer readings together with an automated measurement of these films. Those improvements were applied by Watts to his design of the Seven-Inch USNO Transit Circle for which construction began in 1947; it was placed in service in 1955. These improvements resulted in significant advances in the accuracy of stellar positions and in other astronomical measurements dependent on those fundamental catalogs.

In 1942, Watts suggested the USNO carry out a survey of the marginal zone of the Moon. The purpose was to produce the most detailed map of the lunar limb to date, as well as a precise datum from which to reference lunar topography. The project was delayed by World War II. From 1946 until 1963 Watts struggled with a number of scientific problems inherent in the project, but world politics intervened to give the project a higher priority and bring additional resources to bear.

The United States was in the midst of the Cold War with the Soviet Union for which the premise of mutually assured destruction in the event of a war resulted in substantial strategic preparation. One problem the US military had in launching intercontinental ballistic missiles was that they could not be sure the missiles would hit their targets on another continent. The launch points and target zones were on different mapping datums that would cause errors in targeting.

The Army Map Service was given the mission to link the various continental datums, a problem for which astronomical measurements offered the main solutions available at the time. Specifically, precise timing of transient astronomical events that could be predicted and observed from both continents could be used for that purpose. Astronomical events that would lend themselves to such a project include total solar eclipses in which the appearance and disappearance of Bailey's beads were timed accurately. (See **Edward Halbach**.) Another type of suitable event was a grazing occultation observed from both datums. However, for both the solar eclipse and the grazing occultation observations, accurate charts of the lunar marginal areas, the areas that appear and disappear according to the ever-changing libration of the Moon, would have to be available to increase the accuracy of the datum observations. The Army Map Service provided support to speed the USNO project along. The Lunar Limb Charts (now known as the Watts Limb Charts) were finally published in 1963 as "The Marginal Zone of the Moon," Volume 17 of the *Astronomical Papers of the American Ephemeris*.

The Watts Charts were derived from photographs taken at three locations – 571 photographs at Washington, USA, between 1947 and 1956; 247 photographs taken at Johannesburg, South Africa, between 1927 and 1952; and 49 photographs taken at Flagstaff, Arizona, USA, between 1927 and 1928. The primary telescope used was the Naval Observatory's horizontal refractor. This refractor is of 12.2-m focal length, 12.7-cm aperture (a 5-in. *f*/96), and was built in 1873 by **Alvan Clark**.

The most significant feature of the Watts Charts is their reference to a spherical datum, actually two spherical datums, each with a specific purpose in the use of the charts. The finished product of this work was a series of 1,800 libration frames and a few pages of what became known as the "P & D Charts" for a total of 951 pages of data. Use of the Watts Charts originally involved graphical interpolations of the exact points of interest on the lunar surface. More recently, however, interpolation of the Watts Charts has been computerized by the International Occultation Timing Association [IOTA]. Data reduction of observational data is now remarkably simplified. Watts's finished work has led to highly refined occultation work, leading to other useful information as well, for example the discovery of new double stars from the precise manner in which the light of the star disappears when occulted on a precisely known surface of the Moon. Lunar occultation data have also been used to understand the cloud structures around young T-Tauri stars in the Taurus and Ophiuchus Dark Clouds, and to refine the map of the center of the Milky Way Galaxy.

Watts worked quietly on his demanding projects without seeking publicity for himself. It was the trademark of the work of Watts that he accomplished difficult and demanding work of great benefit to succeeding generations of astronomers without a great deal of recognition for himself. However, honors of various types came his way due to the effect his work had on the astronomical community. He was awarded the honorary degree of doctor of sciences by his *alma mater*, Indiana University, in 1953. Watts received the James Craig Watson Medal from the National Academy of Sciences in 1956. He earned the Federal Distinguished Civilian Service Award in 1959, which was also the year of his retirement from the USNO. Watts served as president of International Astronomical Union Commissions on Positional Astronomy and on the Motion and Figure of the Moon through the 1950s as well as president and chairman of the Astronomy Section of the American Association for the Advancement of Science.

Richard P. Wilds

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Webb, Thomas William

Born **Tretire cum Michaelchurch, (Hereford and Worcester, England), 14 December 1806**
Died **Hardwick, Oxfordshire, England, 19 May 1885**

In many ways the patron saint of British amateur astronomers, Thomas Webb influenced amateurs more broadly around the world through his popular guide to telescopic astronomy, which has been updated and remained in print for over a century. He was the only son of a clergyman, Reverend John Webb, rector of Tretire cum Michaelchurch in the county of Hereford. The elder Webb was a sound classical scholar, and an eminent authority on Norman French, who was frequently called upon to give evidence in Courts of Law on the interpretation of early documents. But he was more particularly devoted to researches on the history of the west of England during the Civil War, and for the greater part of his long life – he lived to the ripe old age of 93 – John Webb was preoccupied with preparing a history of Herefordshire during the Civil War. But his dread of inaccuracy or precipitate thought slowed the work, which was left to his son to complete many years later.

Thomas's mother died when he was still a child, and he was educated entirely by his father. Brought up among books and manuscripts, Webb became precise, studious, and mature for his years. While he showed some aptitude for experimental science, especially electricity, his father insisted that he become a classical scholar. Thus Webb was dissuaded from studying Euclid; otherwise it is almost certain that he would have become a mathematician. His efforts at Latin and Greek, though carried out with diligence, did not progress to his father's satisfaction. In 1826 Webb entered Oxford University as a gentleman commoner at Magdalen Hall. He took his degree in 1829, with second-class honors in mathematics. Webb might have done better had he applied himself more earnestly, for he later admitted that he spent most of his time in the "idleness" of desultory reading in the library.

On leaving Oxford University, Webb was licensed to the curacy of Pencoyd where he remained for 2 years. He took holy orders in August 1831 and became a minor canon of Gloucester Cathedral. Ten years later Webb returned to Tretire and worked as curate under his father. Only in 1852 did he attain to the living of Hardwick, a large but thinly populated parish near the Welsh border. While diligent in the pursuit of his clerical duties – he set out early each afternoon with a knapsack on his back to visit the more remote members of his parish – Webb never lost his early interest in science.

Proficient in German, Webb read **Wilhelm Beer** and **Johann von Mädler** in the original and became the most reliable source of information about German selenographic studies, then the standard, in the English-speaking world. At Gloucester he began routine observations of the Sun, Moon, and planets with a rather modest instrument, a 3.7-in. achromatic refractor by the English maker Tulley. On the recommendation of his close friend and advisor, **William Rutter Dawes**, in 1859 Webb obtained a 5.5-in. refractor by **Alvan Clark**. This was followed by an 8- and then a 9.3-in. Newtonian reflector, both by George With, during the 1860s.

Webb immediately realized that there was still much useful work to be done, especially on the Moon. He wrote:

> A little experience showed that Beer and Mädler have not represented all that may sometimes be seen with a good common telescope. My own opportunities, even when limited to a 3 7/10-inch aperture, satisfied me, not only how much remains to be done, but how much a little willing perseverance might do.

What fascinated Webb above all else was the exciting possibility that the surface of the Moon was still in active condition. His first essay, "On the Lunar Volcanos," had been presented to the British Association as far back as 1838, but not until 1859 did he follow it up with "Notice of Traces of Eruptive Action in the Moon." Here Webb pointed out that while astronomers were generally agreed as to the cessation of such action on a large scale, "this would not necessarily infer the impossibility, or even improbability, of minor eruptions, which might still continue to result from a diminished but not wholly extinguished force." Webb's project of documenting lunar change, which had been all but banished since the publication of Beer and Mädler's treatise *Der Mond* (The Moon) in 1837, set the tone for much of the selenographical work by British amateurs for the next century, preoccupied with seeming minor changes as evidence of the Moon's ongoing geological activity, along with the resurgence of the possibility that the Moon was a living world, "habitable," as Webb expressed the hope, "in some way of its own."

Webb left four notebooks recording thousands of solar, lunar, planetary, and stellar observations. His meticulously detailed notes, all in delightful prose and exquisite calligraphy, were accompanied by hundreds of sketches. Webb made many contributions to **John Birmingham**'s *Red Star Catalog* and also discovered a number of variable stars.

Webb's influential book *Celestial Objects for Common Telescopes* appeared in 1859, the same year as Darwin's *On the Origin of Species*. Bringing a quarter of a century of Webb's experience to the aid of the beginner, it contained comprehensive discussions of telescopes and observing techniques, as well as exhaustive descriptions of the lunar, planetary, and stellar objects accessible to modest instruments, accompanied by historical accounts of the previous astronomers who had viewed the objects under discussion. It was an instant classic, and during his lifetime it passed through several revised and expanded editions with chapters on the Moon updated by **Thomas Elger**. Following Webb's death his friend, *protégé*, and executor, Reverend **Thomas Espin** would edit the fifth and sixth editions. A later edition, edited by **Margaret Mayall**, was published as late as 1962 and is still widely read today.

Thomas Dobbins and *William Sheehan*

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Weigel, Erhard

Born **Weiden, (Bavaria, Germany), 16 December 1625**
Died **Jena, (Germany), 21 March 1699**

Erhard Weigel was a professor of mathematics at the University of Jena, who attempted to rename the classical constellation patterns, replacing them with figures from modern European heraldry. Thus, "Ursa Major," became "The Elephant of Denmark," and "Cygnus" became "The Ruta and Swords of Saxony." Weigel's uranography has not survived him.

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Weinek, László [Ladislaus]

Born **Buda, (Budapest, Hungary, 13 February 1848**
Died **Prague, (Czech Republic), 12 November 1913**

László Weinek directed the German University Observatory in Prague (after 1883) and is chiefly remembered for his extensive drawings and photographs of lunar-surface features. Weinek's father was a government official. Although his family was of German origin living in Hungary, Weinek declared himself to be Hungarian. After graduating from secondary school in Buda, he studied mathematics, physics, and astronomy at the University of Vienna, where he was awarded a doctorate in 1870. A state-sponsored scholarship enabled him to continue postdoctoral studies at Berlin and Leipzig, Germany.

As a young astronomer, Weinek was involved in the Saxonian geodetic work of latitude and longitude determination (1872/1873). He undertook a pioneering role by introducing photographic techniques into astronomy. After completing a study of the measurement errors associated with photographic astrometry, Weinek was chosen to participate in the German expedition to observe the 1874 transit of Venus from Kerguelen Island in the Indian Ocean. He obtained 60 good-quality photographs of the event. After returning to Leipzig Observatory, Weinek analyzed the photographic plates of his own and others' expeditions, with a view toward deriving a more precise value for the Astronomical Unit. He then took part in the astrometric measurements for the Leipzig zone of the *Astronomische Gesellschaft Katalog*. For these contributions, Weinek was elected a member of the Hungarian Academy of Sciences (1879).

Unable to find employment as an astronomer in Hungary, Weinek accepted a position as professor of astronomy at the German University in Prague (1883). Those duties included the directorship of the university's Observatory. There, he became a leading investigator of lunar topographic features by virtue of his hundreds of detailed drawings and from analysis of photographs of the Moon taken at the Lick Obervatory and the Paris Observatory. Weinek's combined treatment of the drawings and photographs brought to light many unrecorded features on the lunar surface. Starting in 1889, he also participated in the international efforts to observe the effects of polar motion by astrometric means. A crater on the Moon has been named for him.

László Szabados

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Weiss, Edmund

Born **Freiwaldau (Jeseník, Czech Republic), 25 August 1837**
Died **Vienna, (Austria), 30 June 1917**

Edmund Weiss directed the University of Vienna Observatory from 1878 to 1910; his expertise in celestial mechanics demonstrated the connections between two periodic comets and their associated meteor showers. Weiss and his twin brother Gustav Adolf (who became a professor of botany at Prague) were raised in England. His father, a well-known physician, was the head of a hydropathic establishment near Richmond. Weiss's knowledge of the English language was likely helpful in shaping his career as an astronomer. But after his father died prematurely, Weiss returned to his homeland and attended the Gymnasium at Troppau, Austrian Silesia, from 1847 to 1855. He then studied mathematics, astronomy, and physics at the University of Vienna. In 1858, he was appointed an assistant at the Vienna Observatory, where **Karl von Littrow** served as director. Littrow came to appreciate Weiss's mathematical abilities and his skill and diligence as an observer. Weiss was awarded his Ph.D. in 1860.

In 1867, **Otto Wilhelm Struve** offered Weiss a position at the Pulkovo Observatory near Saint Petersburg, Russia, but he declined the invitation. Two years later, he received an offer from the Geodetic Institute in Berlin to undertake latitude and longitude determinations. Weiss also refused the latter offer and was rewarded with an *extraordinarius* professorship at the University of Vienna. He was appointed a full professor there in 1875. Weiss married Adelaide Fenzl in 1872; the couple had seven children.

During the 1870s, Viennese astronomers began construction of a new, modern observatory on the hills of Währing beyond the city limits. Weiss was sent to Great Britain and the United States to visit the leading observatories and telescope makers. He later published a report on his impressions in the proceedings of the Deutsche Astronomische Gesellschaft (German Astronomical Society). His visitations led to the purchase of a 27-in. refracting telescope manufactured by Sir **Howard Grubb** of Dublin (at that time the largest refractor in the world) and a smaller 12-in. refractor by Alvan Clark & Sons of Cambridge, Massachusetts, USA.

As Littrow's health declined, Weiss assumed more of the responsibility for planning and supervising the observatory's construction. After Littrow's death in 1878, Weiss was appointed director of the new Vienna Observatory. He retained this position until his retirement in 1910. During his directorship, Weiss equipped the Vienna Observatory with two more instruments: an equatorial Coudé telescope donated by the Viennese Baron Albert von Rothschild, and a "standard astrograph," which was chiefly used for the positional determinations of minor planets and comets.

A majority of Weiss's research publications dealt with orbital determinations and the calculation of ephemerides of comets and minor planets. He perfected new methods for finding the improved orbits of those bodies. Weiss investigated the orbits of meteors and demonstrated an association between the Lyrids and comet C/1861 G1 (Thatcher) and between the Andromedids and comet 3D/Biela. From these associations, he developed the accepted view that meteors are the disintegration products of comets.

Weiss maintained a special interest in traveling to observe unusual astronomical phenomena. He witnessed solar eclipses in Greece

(1861), in Dalmatia (1867), in Aden (1868), and in Tunis (1870). He likewise observed the 1874 transit of Venus from Jassy, and the expected great meteor shower of the Leonids in 1899 from Delhi.

On account of his interest in solar physics and eclipses, Weiss regularly attended the meetings of the International Union for Cooperation in Solar Research (a forerunner of the International Astronomical Union), which was founded by **George Hale** in 1904. Here, his knowledge of the English language was of considerable help to him. Weiss was also appointed to the Council of the Astronomische Gesellschaft from 1881 to 1915, and was a vice president from 1896 to 1913. He held the office of president at the Austrian commission of the International Commission for the Measurement of the Earth. Weiss was made a full member (1883) of the Vienna Academy of Sciences and was awarded an honorary doctorate from the University of Dublin. In 1889, he was appointed a member of the Permanent International Committee of the *Carte du Ciel* project.

At Vienna, Weiss had a high reputation as a lecturer and was aware of the need to interest the public in matters astronomical. He wrote popular articles and published an astronomical calendar that was distributed by the Vienna Observatory. Weiss was also responsible for revising and publishing the seventh and eighth editions of **Johann von Littrow**'s *Wunder des Himmels* (Wonder of the heavens), a well-known textbook, which was first printed in 1834.

Anneliese Schnell

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Weizsäcker, Carl Friedrich von

Born **Kiel, Germany, 28 June 1912**

German theoretical physicist C. F. von Weizsäcker discovered (at about the same time as **Hans Bethe**) the commonest cycle of nuclear reactions that produces energy by converting hydrogen to helium in massive stars. He also revitalized the nebular or Kant–Laplace hypothesis for the origin of the Solar System.

Born into a family of statesmen, theologians, and scientists, Weizsäcker attended schools in eight different countries before beginning the study of physics at the University of Leipzig and obtaining his D.Phil. in 1933 for work with Werner Heisenberg. His diplomat father Ernst von Weizsäcker was sentenced to jail by the Allies at Nuremberg for service under the Nazis, and his brother Richard served as President of the Federal Republic of Germany from 1984 to 1994.

Carl von Weizsäcker initially worked as assistant to Heisenberg at Leipzig, and moved to the Kaiser Wilhelm Institute für Physik in 1936 as a research physicist, becoming *Privatdozent* (lecturer) the next year and lecturing at the University of Berlin. He worked partly with Lise Meitner and Otto Hahn, and his attention turned to applications of nuclear physics to astrophysics. The 1932 discovery of the neutron and its relationship *via* the weak interaction to the proton and neutron enabled Weizsäcker to go beyond the ideas of **Fritz Houtermans** and **Robert Atkinson** and to propose how a nucleus of carbon might act as a catalyst, capturing four protons in succession, dropping off a helium, and going through the same process many times. He published a couple of papers in 1937/1938 on the transformation of elements in stellar interiors.

In 1942, Weizsäcker was appointed associate professor of theoretical physics at the University of Strasbourg. Here he devised a more sophisticated and realistic version of the nebular hypothesis of **Immanuel Kant** and **Pierre de Laplace** for the origin of the Solar System.

Von Weizsäcker argued that the original dust cloud out of which the Solar System was formed would experience turbulence and break up into a number of smaller vortices and eddies. These vortices fell into gradually larger systems with increasing distance. At the boundaries between sets of vortices, conditions were supposed to be suitable for planets to form from the continuous aggregation of progressively larger bodies. His theory was able to resolve the problem of low angular momentum of the Sun and to provide a physical explanation of the Bode–Titius law of planetary distances. While Weizsäcker's theory was not able to resolve all the questions about planetary formation, his work directed a fresh stream of thought into this field and attracted a lot of attention from scientists in the field. Modifications and additions were later proposed by Dirk ter Haar, **Hannes Alfvén**, and **Fred Hoyle**.

In 1944, Weizsäcker returned to the Kaiser Wilhelm Institute and turned to a study of the nuclear reactions that take place in the fission of uranium and the problems of constructing a self-sustaining reactor. In April 1945, he was arrested by Allied forces along with other high-ranking German scientists. During the 8 months they were interned by the British government at Farm Hall, Godmanchester, their conversations were recorded. These form part of the historical record on how far Germany had advanced toward construction of a fission bomb.

After his return to Germany, Weizsäcker joined the staff of the Max Planck Institute for Physics at Göttingen in 1945 and remained there until 1957. During this period he also held an honorary professorship at the University of Göttingen. Then, in 1957, Weizsäcker accepted a position of professor of philosophy at the University of Hamburg. This decision was indicative of his intention to spend more time in thinking, and writing, and with matters of religion and philosophy, while holding an honorary chair at the University of Munich. During the 1960s, he was very active in the peace movement and became a strong spokesman for nuclear disarmament. He relinquished the Hamburg position in 1969 to take up the directorship of the Max Planck Institute on the Preconditions of Human Life in the Modern World in Starnberg in 1970. Weizsäcker retired from this position in 1980 having reached the age of 68. Since 1980 he has been emeritus scientific member (*Mitglied*) of the Max Planck Institute, Munich.

Weizsäcker married Gundalena Wille on 30 March 1937. Their children are Carl Christian, Ernest-Ulrich, Elizabeth (Mrs. Raiser), and Heinrich.

He has received many honors, including the Max Planck Medal in 1957 and 1966, the Goethe Prize (City of Frankfurt, 1958), the Order of Merit for Sciences and Arts (1961), the Arnold Raymond Prize for Physics (1965), the Erasmus Prize (1961), the Templeton Prize for Progress in Religion, and several others. He has also received honorary degrees from several universities.

Weizsäcker is a member of numerous societies. Amongst these are the Max-Planck-Gesselschaft, Deustsche Akademie der Naturforscher Leopoldina (Halle), Deutsche Akademie für Sprache und Dichtung, Göttinger Akademie der Wissenschaften, Sachsische Akademie der Wissenschaften (Leipzig), Österreichische Akademie der Wissenschaften (Wien), and Deutsche Physikalische Gessellschaft.

Y. P. Varshni

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Wendelen, Govaart [Gottfried, Godefried]

Born **Herck-la-Ville, (Belgium), 6 June 1580**
Died **Ghent, (Belgium), 24 October 1667**

Godefried Wendelen demonstrated the uniformity of the precession of the equinoxes. He corrected numerous geographical longitudes and was the first to point out a solar parallax of 14 s. Wendelen also claimed to have discovered Kepler's third law, 8 years before Kepler himself did so.

Wendelen was the son of Nicolas Wendelen and his second wife, Elisabeth Corneli. After having received his first education in Herck-la-Ville, Wendelen went to the Jesuit college at Tournai in 1595 and afterward to Louvain to continue his studies. He subsequently traveled to Marseilles (1599) and Rome (1600). In Digne, Wendelen taught mathematics for a year (1601), where he met **Nicolas de Peiresc** and **Pierre Gassendi**. From September 1604 until April 1612, he tutored the two sons of André Arnaud, Seigneur de Miravail and lieutenant general of the Seneschal's court of Forcalquier. In 1612 Wendelen returned to his birthplace, where he became the supervisor of the local Latin school. In December 1619 he became subdean in Mechelen, and he was ordained priest in Brussels. In June 1620 Wendelen was nominated priest of Geetbets. When he was ordained priest in Herck-la-Ville in 1633, he returned to his birthplace, where he lived until 1648. In that year he became an official at the cathedral in Tournai. Wendelen retired in 1658 and lived the remainder of his life in Ghent.

Wendelen was a convinced Copernican, and was praised by **Galileo Galilei** and **René Descartes**. **Isaac Newton** included him among the 71 authors cited in the *Principia* (1687). Wendelen corresponded with his younger contemporaries **Marin Mersenne**, Pierre Gassendi, and Constantijn Huygens.

Wendelen tackled the problem of the variation of the obliquity of the ecliptic in his *Loxias, seu de obliquitate solis* (1626). It was traditionally thought that the obliquity had decreased from **Eratosthenes** until **Georg Peurbach**, and that it had increased from Peurbach until Wendelen. Wendelen examined the errors in the observations at hand and completed the available data by adding his own observations. He focused in particular on the atmospherical refraction, the solar parallax (which he found to be 1′ by adopting **Aristarchus**' method and using the telescope), and a correction of **Ptolemy**'s inaccurate latitude for Alexandria (which Wendelen improved by relying on information provided by navigators). On the basis of the new parameters Wendelen recalculated all the data, and concluded that the obliquity had been decreasing from **Thales** onward; he also provided a table to calculate the obliquity at any time.

In 1629, Wendelen published the first part of his *De deluvio*, a work that he would never finish. He took the seven floods that had occurred thus far in the history of mankind as his point of departure to reflect on the history of the Earth. In the last chapter, dealing with cosmology, the heliocentric theory was openly present. Wendelen moreover affirmed that he had observed sunspots from 1601 onward, *i. e.*, long before Galilei. He considered a comet to be a mass of fire that is ejected by the Sun and describes an elliptical path.

In his *Eclipses lunares ab anno 1573 ad 1644 observatae* (1644) Wendelen described in detail his observations of eclipses and the advantages they offer, especially for correcting geographical longitudes. His analysis of eclipses showed that the solar parallax only amounts to 14.656″ instead of 1′. The distance between the Sun and the Earth is fixed at 14,656 Earth radii.

Wendelen's Copernicanism clearly surfaced in his *De caussis naturalibus pluviae purpureae Bruxellensis* (1647), a work written on the occasion of the red rain observed by the Capuchins of Brussels. In a later edition, parts of Wendelen's correspondence with Chifflet, Cornelius Giselberti Plempius, **Pierre Gassendi**, and others were appended to the original text. From one of his letters to Gassendi, Wendelen's sympathy for **Johannes Kepler** becomes apparent, even though he thought that the lunar motion described an oval, rather than an elliptical path.

The *Teratologia cometica* (1652) discussed the comets of 1607, 1618, and 1652. Wendelen resumed his theory that comets are ejected by the Sun, similar to the fiery masses that are ejected by volcanoes on the Earth. Instead of being elliptical, however, the comets' path was described as being conchoidal. The heliocentric theory is present in this book, where Wendelen considered the Earth (called the *tertium corpus*) to be one of the planets describing an elliptical path around the Sun.

In 1658, Wendelen resumed a method that he had used before, in his *Luminarcani Arcanorum caelestium Lampas* (1643). This, Wendelen's last published work, is a small treatise containing

12 astronomical propositions that are presented in the form of anagrams. It contains Kepler's third law, which Wendelen possibly discovered independently in 1610. Either way, Wendelen certainly applied it for the first time to Jupiter's satellites. In the preface to this work, Wendelen expressed his belief that eclipses entail predictions for the future. This means that the demand for exact knowledge goes hand in hand with the belief in a celestial influence on earthly phenomena.

Additional work by Wendelen can be found in his manuscripts that are preserved at Brussels and Bruges, and in his correspondence with Pierre Gassendi, Marin Mersenne, Constantijn Huygens, and others.

Fernand Hallyn and *Cindy Lammens*

Alternate name

Godefridus Wendelinus

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Werner, Johannes

Born **Nuremberg, (Germany), 14 February 1468**
Died **Nuremberg, (Germany), probably March to June 1522**

Navigator Johannes Werner started his studies in Nuremberg and continued at the University of Ingolstadt (enrolled: 1484); from the very beginning he showed an inclination toward the exact sciences. In 1490, he was appointed as chaplain in Herzogenaurach, Germany, but he spent the years 1493–1497 studying in Rome. Werner entered the career of a priest, but besides studies of theology he substantially improved his knowledge of astronomy, mathematics, geography, and the Greek language, profiting from discussions with many learned Italian men. After his return to Germany in 1498, he settled finally at the Saint Johannis Church in Nuremberg, where he remained until his death.

In Nuremberg, Werner had frequent contacts with many scholars, including **Albrecht Dürer**, who sometimes needed advice on problems of mathematics and geometry. Werner also earned recognition abroad, and in 1503 he was invited to the emperor's court in Vienna. Later, **Johannes Stabius**, mathematician and historiographer at the Vienna court, prepared an edition of works on geography, which contained the writings of Werner (1514). Other texts of Werner were published separately, some remained in manuscripts, and some were lost.

In astronomy Werner continued the practical work of **Johann Müller** (Regiomontanus). For example, he refined the Jacob's staff (radius), an instrument consisting of two or three wooden rules with scales, which Müller used for measuring the angular distances between stars or other celestial bodies.

An invention of Werner's own was a nomographical tool called the "Meteoroscop" for easy numerical solving of spherical triangles, without the need of tables of trigonometric functions. It consisted of a metal plate with a pointer, divided into four quadrants. In two of them were circles corresponding to coordinate lines on the celestial sphere in the stereographic projection; another two with scales served to determine the sines, as is described in detail in the text *De Meteoroscopis*. The clock on the church in Herzogenaurach and sundials in Rosstal belong to the same category of Werner's handmade instruments.

In order to facilitate numerical computations using trigonometric functions, Werner derived the cosine formula and for the first time also the formula (originally in another, slightly cumbersome notation):

$$2(\sin)a \cdot (\sin)b = \cos(a - b) - \cos(a + b).$$

which was later used (before the invention of logarithms) for replacing multiplication by addition (*e.g.*, by **Tycho Brahe** and **Paul Wittich**). His treatise on the motion of the eight spheres and the statement that precession is an irregular motion drew severe criticism both from **Nicolaus Copernicus** and from Brahe. This treatise appeared in the collection of prints from 1522.

Werner's main achievement was his method of determining the difference of geographical longitudes between two places, later referred to as "the method of lunar distances," which became the principal method used in navigation at sea before reliable nautical chronometers came into use at the end of the 18th century. If the measured angular distances between the Moon and selected bright stars along the ecliptic are compared with the values in tables of lunar motion, which had been computed in advance for the time of a reference meridian, then the difference of the local time and the time at the reference meridian equals the difference of longitudes between the observing place and the reference meridian. This method is explained in comments to **Ptolemy**'s book on geography (contained in the collection of 1514), together with two other methods. One method, less precise, was based on measuring the lunar parallaxes from both places; according to the other, the difference in longitudes was equal to the difference of local times of both observers at the beginning or end of a lunar eclipse. The method of lunar distances triggered an effort to express the sophisticated lunar motion by means of mathematics, which gave strong impetus for the development both of mathematical analysis and celestial mechanics.

Martin Solc

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Wesselink, Adriaan Jan

Born **Hellevoetsluis, the Netherlands, 7 April 1909**
Died **New Haven, Connecticut, USA, 12 January 1995**

Adriaan Wesselink developed new instruments and techniques for the photometric observation of stars, provided powerful methods for the determination of stellar radii, and offered a significant correction to the cosmic distance scale. He was the son of Jan Hendrik Wesselink, a physician, and his wife Adriane Marina Nicolette Stok, a surgical nurse. Wesselink was admitted to the University of Utrecht and studied under **Ejnar Hertzsprung** and **Willem de Sitter**. From 1929 to 1946, he held an assistantship at the Leiden Observatory. His doctoral thesis, completed under Hertzsprung's supervision in 1937, examined the light curve of the eclipsing binary star, SZ Camelopardalis. Wesselink employed an objective grating, which provided multiple diffraction images with precisely known photometric ratios, to obtain the star's high-resolution light curve. In 1936, he and two colleagues applied another differential technique, involving size-graded mirrors, to the Sun (in deep partial eclipse), to derive a more accurate value for its limb-darkening function.

In 1939, Wesselink introduced the notion of relaxation oscillations to account for the asymmetries in the light curves of Cepheid variable stars. More importantly, he developed, independently of **Walter Baade**, a new method for determining the radius of a pulsating variable star. This technique was first demonstrated on the star δ Cephei in 1946. Here, Wesselink compared simultaneous measures of the star's color index and its radial velocity. He reasoned that if the pulsation hypothesis was correct, then brightness differences having identical color indices could be due only to changes in size. He then computed the star's mean radius (38 solar radii) and its variation over the pulsation cycle. In this way, Wesselink demonstrated the validity of the pulsation hypothesis with minimal assumptions, mainly, that a single-valued relation exists between the surface brightness and the color index only for the star being analyzed.

During World War II, Wesselink was one of a small group who remained in the Netherlands to look after the Leiden Observatory. In 1943, he married Jeanette van Gogh; the couple had three children.

After the war, Wesselink was appointed by **Jan Oort** to supervise the work at Leiden's southern field station, the Union Observatory in Johannesburg, South Africa (1946–1950). Stronger research opportunities attracted him to the nearby Radcliffe Observatory in Pretoria, South Africa, where he became chief assistant and adjunct director (1950–1964). Working with **Andrew Thackeray** and later with Michael Feast, Wesselink contributed to studies of the B stars of the southern Milky Way. More importantly, this trio detected RR Lyrae stars in the Magellanic Clouds, thereby confirming expansion of the distance scale of the Universe and solving a host of related problems. In the process, Wesselink demonstrated the existence of a significant amount of interstellar dust in the Small Magellanic Cloud.

In South Africa, Wesselink mastered techniques of photoelectric photometry and learned of a new device to observe variable stars differentially: the Walraven photometer (after Théodore Walraven). This instrument may be classified as a "two-star" photometer, the analog output of which was related to the brightness difference between two stars. The device was an antecedent of later chopping, gated, and pulse-counting versions constructed at the University of Calgary in the early 1980s under the title "Rapid Alternate Detection Systems" [RADS].

In 1964/1965, Wesselink became a research associate in the Astronomy Department at Yale University and, from 1966 to 1977, executive director of the Yale–Columbia Southern Observatory at El Leoncito, Argentina. His work at Yale brought him back to his earlier interests in color indices and surface brightnesses. He derived a general relation between these two quantities from stars the radii of which were precisely known through occultations or interferometry; this was widely recognized as a further important contribution.

Although he taught many undergraduates while at Yale, Wesselink had but two Ph.D. students: Carol Ann Williams, a celestial mechanics student; and E. F. Milone, the writer of this essay. Both went on to academic careers. Wesselink retired from Yale in 1977, but maintained an interest in astronomy even after suffering his first stroke. On occasion, he was invited to offer his perspectives at meetings held on stellar pulsation.

A quiet, unassuming person, Wesselink received but few awards during his lifetime, beyond recognition for the eponymous Baade-Wesselink method. He was elected a fellow of the Royal Astronomical Society and served as president of the Astronomical Society of South Africa. He enjoyed a brief turn in the spotlight in 1969 when his 1948 theory of a shallow layer of dust on the Moon's surface, deduced from thermal measurements and conductivity considerations, was proven accurate by the image of astronaut Neil Armstrong's footprint on the Moon.

Wesselink was a resourceful investigator. Once, when he wanted to observe an extremely faint object for which an exposure of many hours was required, he persuaded the manager of the city of Pretoria to arrange an extensive power blackout during the exposure (with the exception of the observatory!), thus darkening the sky sufficiently to produce the intended result.

Wesselink loved a good joke. He once told with glee about the time two well-known astronomers visited him in South Africa. His children came running up and announced that two astronomers, "Egg and Sandwich" (Eggen and Sandage), had arrived.

Taped interviews of Wesselink, obtained in 1977 and 1978 by D. H. Devorkin, may be found at the Niels Bohr Center for the history of Physics, American Institute of Physics.

Eugene F. Milone

Acknowledgement

The author would like to acknowledge discussions with Micheal Feast, Jan Wesselink, William van Altena (and contributions from Dorrit Hoffleit, Carlos Lopez, and Carol Ann Williams), Adriaan Blaauw, and, much earlier, Leendert Binnerdijk.

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Weyl, (Claus Hugo) Hermann

Born **Elmshorn, (Schleswig-Holstein), Germany, 9 November 1885**
Died **Zürich, Switzerland, 8 December 1955**

German–Swiss–American mathematician Hermann Weyl appears to have been the first to write the general-relativistic equations of cosmology in a form in which the galaxies could be regarded as staying at fixed coordinate locations (in what are now called comoving coordinates) while the cosmic expansion was carried by a single function out in front of the rest of the equations. He also gave his name to an important mathematical entity called the Weyl tensor.

The son of Anna Dieck and Ludwig Weyl, a bank director, Weyl was educated at the Gymnasium at Altona (site of what was then a major observatory), whose headmaster sent him on to work at Göttingen with David Hilbert, a relative of the headmaster's. Weyl completed a doctorate and postdoctoral *Habilitation* in 1910 with a dissertation on a particular form of differential equations. He remained at Göttingen and continued his mathematics research there until 1913, working on various aspects of functional analysis.

That year was marked by three major changes in Weyl's life. He married Helene (Hella) Joseph, a translator of Spanish literature. His first book, *Die Idee der Riemannische Flachen*, dealing with Riemannian surfaces, an area of mathematics he later applied in relativity theory, was published. He was offered an opportunity to remain at Göttingen and assume the chair being vacated by the retiring **Felix Klein**, but chose instead to accept an appointment at the Eidgenossische Technische Hochschule [ETH] (Swiss Federal Institute of Technology) in Zürich.

At the ETH Weyl met **Albert Einstein**, who by then was working on general relativity, and welcomed the opportunity to work with him for approximately a year. In particular, Weyl found himself strongly interested in the application of tensor calculus to the representation of space-time, which served to clarify some of Einstein's concepts. However, as a German citizen, with World War I under way, he was drafted into the German army in 1915. In 1916, at the urgent request of the neutral Swiss government, he was discharged and returned to the ETH.

In 1918 Weyl's second book, *Raum, Zeit, Materie*, later translated as *Space, Time, Matter*, was published, a comprehensive exposition of relativity theory in terms of differential geometry. It went through five editions in rapid succession, the fifth bearing the date 1923.

During 1918/1919, Weyl attempted to derive a unified field theory for electromagnetism and gravitation. Though he abandoned that effort as unsuccessful, his concept of gauge invariance remained fundamental for cosmology. Moreover, Weyl was able to relate gauge invariance to charge conservation.

Over the next decade, Weyl alternated his attention and work among basic mathematics, including its philosophical foundations, mathematical cosmology, and the mathematical foundations of quantum theory. In 1926, as the "new" quantum theory emerged, he was in regular communication with **Erwin Schrödinger** at the ETH and the physicists at the Göttingen school, notably Max Born, Werner Heisenberg, and **Pascual Jordan**. Weyl's third book, *Gruppentheorie und Quantenmechanik*, appeared in 1928, followed by an expanded second edition in 1931.

Weyl's contributions to physics are germane to cosmology in a broad contemporary view. In the 1931 edition of the group theory book he included an analysis of Paul Dirac's relativistic equation for the electron, showing that the positive particle its solutions allowed could not be the proton because the equation constrained its mass to be identical to that of the electron. The positron, thus predicted, was found experimentally by **Carl Anderson** in 1932.

In 1927, Weyl had analyzed Wolfgang Pauli's hypothetical neutrino, and derived an equation then thought to be inadequate because it lacked the expected symmetry. Only after the experimental discovery in 1957 of the nonconservation of parity, by Chien-Shiung Wu and her collaborators, was it realized that Weyl's equation had predicted it, decades before the hypothesis published by T. D. Lee and C. N. Wang. The equivalence of mathematical symmetry and physical conservation had been established by Emmy Noether in 1919, but the predictive power of Noether's theorem was not fully realized for many years.

Over the same years, Weyl's work on cosmology continued and progressed. In the early 1920s he showed that the redshifted galactic spectra reported by **Vesto Slipher** required an expanding Universe rather than the stationary models postulated by Einstein and by **Willem de Sitter**, although de Sitter's allowed for redshifts. However, Weyl's postulate on the redshifts led to his model showing all geodesic world lines diverging from a common point as an origin, never intersecting in finite space-time, and projected back as converging toward negative infinity in the past. He thus postulated that all galaxies had a common origin in the very distant past, and that expansion was therefore required. His postulate also enabled him to define cosmic time. Weyl's paper, "Redshift and Cosmology," appeared in 1930.

That year the Weyls and their two sons, Fritz Joachim (also a mathematician) and Michael, moved back to Germany. Weyl had at last accepted an appointment to the faculty at Göttingen, following Hilbert's retirement. However, as the political situation in Germany became increasingly ominous, the Weyls chose to immigrate to the United States in 1934 while it was still possible to do so openly. Weyl was then appointed to the faculty of the Institute for Advanced Study at Princeton University, where Einstein had preceded him. The Weyls were familiar with Princeton since he had spent the year 1928/1929 as a visiting professor at the university.

At the institute, Weyl was able to resume research in several areas of mathematical physics, including spinor theory. His last book, other than revisions and reminiscences, was *The Classical Groups: Their Invariants and Representations*, which was published in 1939.

Weyl became an American citizen in 1939. In 1940 he was elected to the US National Academy of Sciences. He was also a foreign member of the Royal Society (London) and a corresponding member of the Paris Académie des sciences. During World War II, Weyl interrupted his research and carried out analyses on fluid dynamics and shock waves pertinent to national needs. This applied work as well as his basic research led to papers that appeared throughout the 1940s, including one in 1944 pertinent to relativity theory.

In 1948, Hella Weyl died; in 1950, Hermann married Ellen Lohnstein Bär, a sculptor. He retired from the institute in 1951, and marked that occasion with a retrospective book, *Symmetry*, published in 1952. Thereafter, the Weyls divided their time between Princeton and Zürich. The revised and translated version of his first book, *The Concept of a Riemannian Surface*, appeared in 1955. That year, Weyl learned that he had overstayed the time allowed for naturalized American citizens to remain out of the country, and was barred from returning to the United States until a legal exception could be arranged. Unfortunately, he died of a heart attack while still in Zürich.

Weyl's contributions to mathematics, physics, cosmology, and philosophy comprise 150 papers and books. Roger Penrose declared him to be "the greatest mathematician of [the 20th] century."

Frieda A. Stahl

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Wharten, George

Born **1617**
Died **1681**

English mathematician George Wharten compiled "royalist" (Copernican) almanacs starting in 1641.

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Wheeler, John Archibald

Born **Jacksonville, Florida, USA, 9 July 1911**

American theoretical physicist John A. Wheeler is very often cited for having coined the phrase "black hole," but his most lasting impact has been as the founder and mentor of an American school

of scientists who have applied the ideas of general relativity to problems in astrophysics. Corresponding groups in Russia (the former USSR) and England (United Kingdom) are associated with the names of **Yakov Zel'dovich** and Dennis Sciama.

Wheeler is the son of librarians Joseph Lewis and Mabel Archibald Wheeler. His marriage to Janette Hegner in 1935 produced three children.

In 1927, Wheeler enrolled at Johns Hopkins University in a program that led directly to a Ph.D. without intermediate degrees. He received his doctoral degree in 1933 at age 21 with a thesis on the theory of absorption and scattering of light by helium, under the direction of Karl Ferdinand Herzfeld. Wheeler used a National Research Council fellowship to spend the years 1933–1935 working with Gregory Breit at New York University and with **Niels Bohr** in Copenhagen. He was appointed to a faculty position at the University of Chapel Hill, North Carolina, USA, in 1935 and joined the faculty of Princeton University in 1938. During World War II, Wheeler worked on the atomic-bomb project, at the Metallurgy Lab at the University of Chicago (1942/1943), and as a consultant to E. I. du Pont de Nemours & Company, at the Hanford reactor site (1944/1945).

Returning to Princeton, Wheeler was promoted to associate and then full professor of physics and was named to the Joseph Henry chair in 1966, from which he retired in 1976. He then became director of a center for theoretical physics at the University of Texas at Austin for another decade, and retired back to Princeton as professor Emeritus in 1986.

Most of the work for which Wheeler is known was carried out at Princeton—much of it in collaboration with students. His early research (1933–1955) centered on atomic nuclei, elementary particles, and the interaction of radiation with matter. Before going to Princeton, he contributed to the theory of the scattering of light by light (with Breit, in 1934, making a prediction that was finally confirmed experimentally in 1997), to a way of describing quantum-mechanical processes called the S-matrix (1937), and to a first theory of nuclear rotation (in 1938, with **Edward Teller**). Wheeler's famous work on the theory of nuclear fission was completed at Princeton (in 1939, with Bohr, very soon after the discovery of fission).

Wheeler's best-known Ph.D. student was Richard P. Feynman, who completed his Princeton doctorate in1942. During World War II, Wheeler and Feynman were occasionally able to find time at Los Alamos to work together, resulting in two notable papers published in 1945 and 1949 on "action at a distance" (electrodynamics without fields). They showed that the one-way flow of time observed in electromagnetic phenomena results from the enormous amount of matter in the Universe, and that in a hypothetical universe containing only few particles, time would observably run in both directions, with the future affecting the past.

Other Wheeler contributions included a study of the "universal" weak interaction (in 1949, with Jayme Tiomno), a way of looking at the structure of atomic nuclei that accounted for their sometimes very nonspherical shapes (in 1953, with David Hill), the use of muons to probe nuclear properties (1953), and a theory of scattering useful in molecular as well as nuclear physics (in 1959, with Kenneth Ford).

In 1952, Wheeler requested and was granted approval to offer the first-ever course in relativity theory at Princeton University. This triggered an interest in gravitation and relativity that dominated most of his remaining career. He began by pushing the theory to its limits, far from the tiny effects that had initially validated it (the advance of the perihelion of Mercury, the deflection of starlight by the Sun, and the gravitational redshift of solar radiation). Wheeler studied, for example, the possibility of radiation so intense that it held itself together gravitationally. This "geon" (1955) he later showed to be unstable. But in some manifestation—electromagnetic waves, gravitational waves, or neutrinos—he suggested, geons could have had transitory existences, making them potential sources of gravitational radiation.

Wheeler's attention then turned to gravitational collapse, which had been studied as early as 1939 by **J. Robert Oppenheimer** and colleagues. With Tullio Regge, he showed that a Schwarzschild singularity could be a stable entity (1957). Even in his first paper on relativity (1955), Wheeler already was exploring links between gravitation and quantum theory, and soon (1957) he introduced the idea of "quantum foam," pointing out the significance of what he called the "Planck length" and "Planck time" as measures of the scale of quantum fluctuations in spacetime.

Working with Charles Misner on an "already unified field theory"—physics built on curved empty space only (1957)—Wheeler studied and named the "wormhole," a hypothetical conduit between remote points of a multiply connected space–time geometry (leading others to speculate about the wormhole as a mechanism of time travel). He and Misner went on to suggest the idea of "charge without charge"—that is, the ends of wormholes disgorging and engorging lines of electric field to give the appearance of sources and sinks of field.

With various students, Wheeler explored all the possible fates of cold, baryonic matter (1958). He likes to say that he fought against the idea that matter can collapse to a singularity, looking for and hoping to find a rescue from this fate in quantum theory and elementary-particle physics. When Wheeler concluded that nothing could stop the collapse of a sufficiently massive body after its fuel is exhausted, he gave the resulting entity a name, "black hole" (coined in 1967 and first used by him in print in 1968). He then became a leader in working out the properties of black holes. To encapsulate the idea that a black hole is characterized by only its mass, charge, and spin, he introduced the phrase, "a black hole has no hair." In the monograph *Gravitation* (published in 1973 and still in print), Wheeler, Misner, and Kip Thorne laid out the theory of gravitational physics in more than 1,200 pages, much of the content developed by Wheeler with Misner, Thorne, and other students.

In the realm of quantum theory, Wheeler put forward the idea of a "delayed choice" experiment in which a decision to check whether a photon followed one of two possible paths, or followed both paths at once, is made *after* the photon is well on its way through the apparatus. The 1978 conclusion (that the counter intuitive predictions of quantum theory will be borne out) was tested in a laboratory experiment by Carroll Alley and others in 1984.

Throughout his career, Wheeler has served the scientific community and the United States government in many ways and received many honors. With **Lyman Spitzer**, he founded Project Matterhorn in Princeton and contributed to the development of thermonuclear weapons (1951-1953). (Matterhorn later evolved into the Princeton Plasma Physics Laboratory.) An outgrowth of his 1958 "Project 137" was the "Jasons," a group of informal advisors to the government on technical aspects of military matters. Wheeler was president of the American Physical Society (1966) and served as an advisor to Oak Ridge National Lab, the Los Alamos Scientific Lab, the Battelle Memorial Institute, and a number of other organizations. He holds honorary degrees from a dozen institutions in several countries. Wheeler received the National Medal of Science in 1971 and the Wolf Prize in Physics in Israel in 1997. He is a member of the United States National Academy of Sciences and the American Philosophical Society, among other professional and honorary organizations.

Kenneth W. Ford

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Whewell, William

Born **Lancaster, Lancashire, England, 24 May 1794**
Died **Cambridge, England, 6 March 1866**

William Whewell was a philosopher of science and a central figure in early Victorian science and mathematics whose astronomical work focused upon tides. Born the eldest son of a carpenter, he attended the grammar school at Heversham, Westmorland, and then entered Trinity College, Cambridge, graduating second wrangler. He became a fellow of the college in 1817, taking his M.A. degree in 1819 and his D.D. degree in 1844.

By the first quarter of the 19th century, French mathematicians, applying analytical methods to Newtonian physics, had established a supremacy over British mathematicians. In 1819, the year Whewell helped form the Cambridge Philosophical Society, he published his first textbook, *An Elementary Treatise on Mechanics*, the first English text on applied mathematics that consistently used continental symbols and became the standard for undergraduates at Cambridge. With his second textbook, *A Treatise on Dynamics* (1823), Whewell became a leading agent for French analytical methods in Britain. He went on to hold professorships first in mineralogy (1828), then moral philosophy (1838); ultimately he accepted the mastership of Trinity College, Cambridge (1841), an appointment he held until his death.

At Cambridge, Whewell developed one of the foremost mathematical curricula in history. A zealous and prolific researcher, he published significant works in experimental physics, crystallography, mineralogy, physical astronomy, science education, architecture, poetry, and religion, along with a bewildering number of more popular reviews, lectures, and sermons. He was the inventor of the self-registering anemometer, and the originator of many new scientific terms, including "ion," "cathode," "Eocene," "Miocene," "physicist," and "scientist." Whewell is best known for his multivolume *History of the Inductive Sciences* (1837) and his equally impressive *Philosophy of the Inductive Sciences* (1840), both unrivaled in their day. These works helped to define what "science" was in the early Victorian era, an important period in the professionalization of the sciences.

Whewell's work in history and philosophy, and his own researches in physical astronomy, were intimately linked; in the mid-1830s, Whewell composed his *History*, outlined his *Philosophy*, and published his most extensive tidal researches. Physical astronomy, the "queen of sciences" according to Whewell, had reached a state of maturity that no other science could emulate. He referred to it as the only complete science, and it was central to both his

History and his *Philosophy*. Whewell laid out a complete philosophy of scientific methodology. His *History* focused on the gradual ascension of scientific knowledge from facts, to phenomenological laws, and finally to causal laws. Each science began with a "prelude" in which a mass of unconnected facts predominated. The act of "colligation" by the scientist brought about an "inductive epoch" where a useful theory was formed through the creative role of the scientist. A "sequel" followed where the successful theory was refined and applied. Whewell's historical analysis of physical science provided the basis for his philosophy of science.

Deeply influenced by **Immanuel Kant**, Whewell, like Kant, emphasized the creative role of the mind and the need for bold unifying conjectures that far surpassed the empirical evidence. Because a "boldness and license of guessing" was a necessary aspect of all progress in science, Whewell also believed the scientist must be equally prepared for testing each hypothesis. Though a correct theory should be able to account for all of the observed facts and predict new ones, the true test of a scientific hypothesis came when it explained "cases of a kind different from those which were contemplated in [its] formation." According to Whewell, cases in which "inductions from classes of facts altogether different have thus jumped together," a peculiar feature he termed "consilience of induction," belonged only to the best-established theories in the history of science.

Whewell's own research in physical astronomy was in what he termed "tidology." Between 1833 and 1850, he wrote 14 major papers on the study of the tides, along with numerous shorter essays. By following the analogy of physical astronomy, his model science, and **Johannes Kepler**, his model scientist, Whewell sought to have masses of observations made around the globe to determine the phenomenological laws of the tides. He followed two major lines of research: The first advanced the earlier work of John William Lubbock and entailed an analysis of long-term observations to determine the tidal constants at the major ports in Great Britain, including the establishment of each port and the effects of the parallax and declination of the Sun and Moon. His second line of research was unique and entailed an analysis of short-term but simultaneous observations along the entire coast of Great Britain, and eventually Europe and America. In July 1835, Whewell organized a "great tide experiment" where the tides were measured every 15 minutes for a fortnight at over 650 tidal stations in nine countries, including Great Britain, France, and the United States. He used these simultaneous measurements to draw a map of "co-tidal lines" to determine the motion of the tides across the ocean.

Whewell's work on the tides was modestly successful. He combined his method of analyzing long-term observations with simultaneous short-term measurements in a unique fashion to determine the course of the tide around the British coast. He determined the empirical laws for the parallax and declination of the Moon and Sun, and quite correctly noted the importance of the diurnal inequality – his prize analysis – for any future theory. Along with **John Herschel**, Whewell pioneered the graphical representation of data and its use in theoretical investigations. He used his unique "graphical method of curves" throughout his tidal studies, and, in turn, used his tidal researches as an explanation of the process of data reduction and analysis in his *Philosophy*. Thus, though Herschel had laid out the graphical method in 1833, it was Whewell who explained it for the first time in combination with other methods of data analysis, such as the method of residues, and popularized its use through the pages of his *Philosophy*. He received the Royal Society's Royal Medal for his efforts in 1838.

Whewell held many titles, including fellow of the Royal Society of London and the Royal Astronomical Society, and honorary membership in numerous foreign societies.

Michael S. Reidy and *Malcolm R. Forster*

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Whipple, Fred Lawrence

Born **Red Oak, Iowa, USA, 5 November 1906**
Died **Cambridge, Massachusetts, USA, 30 August 2004**

American cometary astronomer Fred Whipple formulated the modern theory of the structure of comet nuclei, the "dirty snowball" or "dirty iceberg," in which a matrix of frozen water, carbon dioxide, and other ices embeds solids including interstellar dust grains. The son of Henry Lawrence Whipple and Celestia (*née* McFarland) Whipple, he spent his first 14 years on an Iowa farm. After the family moved to Long Beach, California, he graduated from high school there. Whipple enrolled as a mathematics major at Occidental College, switching after one year to an astronomy major at the University of California [UC] at Los Angeles where he received an AB in 1927. His graduate work at UC Berkeley and Lick Observatory was supported by a teaching assistantship; he received a Ph.D. in 1931 with a thesis on radial velocity curves of Cepheid variables under the direction of **Armin Leuschner**. The next year, Whipple accepted a position at the Harvard College Observatory [HCO] under the direction of **Harlow Shapley**, and remained associated with the various astronomical institutions in Cambridge, Massachusetts, thereafter, first as director of the outlying Oak Ridge Station (1932–1937), then as a faculty member of HCO (1937–1977 with secondment to the Office of Scientific Research and Development 1942–1945), retiring as Phillips Professor of Astronomy in 1977. Whipple also served a term (1949–1958) as chair of the Harvard astronomy department. He concurrently helped arrange the relocation of the Smithsonian Astrophysical Observatory [SAO] to Cambridge in 1955, serving first as its director and then, after an institutional merger in 1973, as director of Harvard–Smithsonian Center for Astrophysics until 1977.

Whipple married Dorothy Woods in 1928, the marriage ending in divorce in 1935 after the birth of a son. His second marriage to Babette Frances Samuelson in 1946 produced two daughters.

Soon after the discovery of Pluto in 1930 by **Clyde Tombaugh**, Whipple collaborated with another graduate student to attempt to determine its orbit from a very limited stretch of data. One of their several possible orbits turned out to be essentially correct. During the period 1936–1941, he collaborated with **Cecilia Payne-Gaposchkin** on interpretation of the spectrum of Nova

Hercules and an attempt to understand the then completely mysterious spectra of supernovae, focusing on the very bright 1937 event now known to have been a Type Ia. Their conclusion that the dominant contributions must be very greatly broadened lines of common elements was essentially correct. Whipple's estimate of the total light production of supernovae, allowing for changes in the extragalactic distance scale since 1939, also came close to the modern value.

Virtually all of the rest of Whipple's work concentrated on meteors, comets and dust in the Solar System. His war work had two parts: designing strips of aluminum-foil chaff to be deployed from Allied aircraft and confuse enemy radar, and devising a thin absorbing shield to protect high-flying aircraft from meteorite impacts. Spacecraft later carried such Whipple shields.

Whipple began observing meteors by photographing them from several sites to get three-dimensional trajectories. He soon verified his underlying assumption that most of them share cometary kinematics. His meteor spectra showed silicon and iron, and Whipple concluded that comets should also contain heavy elements in dust form as well as come from a remote ring of progenitors outside the orbit of Pluto, as suggested in 1932 by **Ernst Öpik** and later refined by **Jan Oort** for whom the comet cloud is named. The conclusion that meteors are cometary debris sheds light on a long-standing problem, apparent deviations of cometary orbits, including that of the most famous, 1P/Halley, from precise periodicity. Ejecting the material that becomes meteoroids and then meteors if they intersect with the Earth's atmosphere causes an "equal and opposite force" on the comet, which can change its orbit.

By 1949 Whipple had concluded that comets consisted of a solid nucleus of frozen water, methane, carbon dioxide, carbon monoxide, and ammonia with embedded dust particles of silicates and hydrocarbons. As the nucleus approaches the Sun, the ices volatilize sequentially, and the gases and dust form a coma and two tails responsible for the standard appearance, while jets of ejecta can change the orbit. He further refined the model over the next decade.

As director of SAO, Whipple expanded its mission from effects of solar radiation on the Earth to include the small bodies of the Solar System and extra-solar-system astronomy. He participated in the early years of the space program, developing cameras and tracking teams to follow artificial satellites and continued with the program throughout his career. He became a member of the scientific team of the National Aeronautics and Space Administration's [NASA] CONTOUR (Comet Nucleus Tour) mission in 1998. (The mission failed at the stage when the main engine should have ignited to take it out of near Earth orbit.)

Whipple served on advisory panels for NASA, the National Science Foundation, and the US Army, US Navy, and US Air Force; maintained memberships in a number of professional organizations; held a vice presidency of the American Astronomical Society (1962–1964); and served as president of the commission of the International Astronomical Union that deals with the physical nature of comets and other small bodies. He wrote popular books as well as more than 150 research publications and was a devotee of science fiction. Whipple held a number of honorary degrees; received medals and other honors from the US National Academy of Sciences, the American Academy of Arts and Sciences, the Royal Astronomical Society (London), the Astronomical Society of the Pacific, the American Association for the Advancement of Science, the Meteoritical Society, and the US government; and has a minor planet named for him. Between 1932 and 1942, Whipple also discovered six comets (on Harvard photographic plates) that are named for him, including 36P/Whipple.

Frieda A. Stahl and Virginia Trimble

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Whiston, William

Born **Norton-Juxta-Twycross, Leicestershire, England, 9 December 1667**
Died **Lyndon, Leicestershire, England, 22 August 1752**

William Whiston popularized Newtonian physics and astronomy, which he incorporated into his own cosmogony that also reached wide audiences. He was born to Josiah and Katherine Whiston. Whiston's father, the rector of Norton, intended his son to become a clergyman. A year after his father's death in 1685, William matriculated at Clare Hall, Cambridge. In 1693, Whiston became a senior fellow of Clare and was ordained in the Church of England. At Cambridge, he continued his study of mathematics and Cartesian mechanical philosophy, but he was converted shortly afterward to the physics that **Isaac Newton** presented in his *Principia* (1687).

After meeting Newton in 1694, Whiston published his first book, *A New Theory of the Earth*, with a dedication to Newton. Whiston's cosmogony, the first book-length popularization of Newtonian physics and astronomy, was an attempt to correct Thomas Burnet's *Sacred Theory of the Earth*, which had used Cartesian physics to explicate the biblical accounts of creation and the Flood. Whiston employed Newtonian physics and astronomy to account for physical mechanisms used by God to create the Solar System and bring about the Noachic Deluge and also to describe the final apocalyptic conflagration. The chief mechanism came from Whiston's providentialist, Newtonian cometography. Whiston proposed that planets were comets captured by the Sun's gravitational pull. The most striking feature of the *New Theory* is its catastrophist model of Earth history; for example, the close passage of a comet accounts for the diurnal rotation of the Earth and the distortion of the Earth's orbit from a circular to elliptical shape. Whiston attributed the geological strata and buried marine fossils to the Noachic Flood, brought about by a later close passage of a comet that distended the Earth's crust, causing it to break open and release the subterranean waters. The rain described in the Genesis account of the Flood he attributed to escaping vapors from the comet, the tail of which he believed the Earth passed through during the Deluge. Whiston predicted that the gravitational attraction of yet another comet would pull the Earth out of its solar orbit in the future, leaving the Earth to travel freely through the Universe. Whiston answered some of his critics in his *A Vindication of the New Theory* (1698) and *A Second Defence of the New Theory* (1700).

Whiston became rector of Lowestoft cum Kessingland on the Suffolk coast in 1698, but returned to Cambridge in early 1701 after being asked to lecture as Newton's deputy. This appointment may have been, at least in part, the result of the *New Theory*, which Whiston claimed had been viewed with favor by Newton. Whiston evidently impressed the electors: He was elected Lucasian Professor in May 1702, shortly after Newton's resignation in late 1701.

Whiston lectured on astronomy, mathematical physics, and ancient eclipses. Instrumental in the election of **Roger Cotes** to the Plumian Professorship of Astronomy and Experimental Philosophy, Whiston went on to collaborate with Cotes in Cambridge's first experimental lecture course, which began in May 1707. While he was Lucasian Professor, Whiston published Newton's lectures on algebra (*Arithmetica universalis*, 1707). Unlike his immediate predecessor, Whiston attempted to reach his undergraduates with his lectures and textbooks, including various editions of Euclid's *Elements*.

After Whiston became aware of Newton's antitrinitarian heresy, he began in 1708 to preach antitrinitarian views openly, much to the consternation of his Cambridge colleagues. Characteristically, Whiston refused to be dissuaded by friends who warned him away from such a legally dangerous path; on 30 October 1710 the college heads expelled him from Cambridge and his professorship. Newton remained silent through Whiston's trial by the Convocation of Clergy that followed, and by 1714 broke with his quondam disciple completely.

With only the meager revenues from a small farm to support his growing family, Whiston moved to London and set himself up as a private mathematics tutor. By 1712, he began public lectures on experiments and formed a partnership with the instrument-maker Francis Hauksbee, Jr., whose shop, a few doors down from the Royal Society, provided the venue. In collaboration with engraver and instrument-maker John Senex, Whiston published in 1712 a much-copied chart of the Solar System illustrated with the paths of 21 comets. The solar eclipses of 1715 and 1724 provided the enterprising Whiston with further opportunities to secure income from astronomy; he delivered lectures on these events and, along with **Edmond Halley**, produced some of the earliest eclipse charts. Whiston continued to bring together his theological and astronomical interests in his *Astronomical Principles of Religion, Natural and Reveal'd*. Written in accessible prose and published with engravings of the Solar System, this book served as an effective popularization of both the new astronomy and natural theology.

Although Newton blocked his nomination, Whiston made several appearances as a nonmember at meetings of the Royal Society, including presentations of magnetic experiments in 1720 and 1722. In 1734, he made a presentation to the society on a reflecting telescope he had invented. Whiston continued to devote energy to the longitude problem and the mapping of the coast of Britain in the 1730s and 1740s, resulting in *An Exact Trigonometrical Survey of the British Channel* (1745).

Whiston made few original contributions to astronomy aside from his cometographical theories, but he played a pivotal role in the dissemination of Newton's work through his popularizing program. A major luminary in the catastrophist tradition of Earth history, Whiston's *New Theory* helped foster mechanical explanations (including impact theory) to describe the origin and development of the Solar System. Although his own schemes proved unsuccessful, Whiston played a pivotal lobbying role in the creation of the Board of Longitude and the Longitude Act. Whiston's influence can also be detected in the work of his grandson, astronomer and meteorologist Thomas Barker (1722–1809), whose *An Account of the Discoveries Concerning Comets, with the Way to Find Their Orbits* (1757) played a minor but important role in the history of cometography.

Stephen D. Snobelen

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Whitehead, Alfred North

Born **Ramsgate, Kent, England, 15 February 1861**
Died **Cambridge, Massachusetts, USA, 30 December 1947**

Alfred Whitehead was a leading mathematician and philosopher of the 20th century, whose works addressed theoretical physics and cosmology. Whitehead's early education was obtained at Sherborne in Dorset, a school founded in the 8th century. In 1880, he was admitted to Trinity College, Cambridge University, where two centuries earlier, **Isaac Newton** had laid down what he thought were the fundamental laws of the Universe. Upon his graduation in 1884, Whitehead was elected a fellow of his college. Although he held strong interests both in mathematics and philosophy, he chose the former because, as he said, "Mathematics must be studied; philosophy should be discussed." One of Whitehead's most important contributions to both disciplines was achieved through his collaboration with former student Bertrand Russell, on their three-volume *Principia Mathematica* (1910–1913), in which the pair took on the gargantuan task of translating all of mathematics into logic. In 1890, Whitehead married Evelyn Willoughby Wade; the couple had three children.

Whitehead resigned his post at Cambridge in 1910 and relocated to London. The following year, he obtained a position at University College but in 1914 was appointed to the chair of applied mathematics at the Imperial College of Science and Technology.

In 1924 (at the age of 63), Whitehead left England to join the philosophy department at Harvard University. He had, in years previous (*e. g.*, *The Concept of Nature*, 1920), already turned his attention to the conceptual analysis typical of philosophers of science. At Harvard, however, he began work on his own great system of *process philosophy*, a theory according to which all things, even atoms – which Newton had conceived as being most real – are but intellectual abstractions that have no mind-independent existence. This aspect of Whitehead's philosophy resembles the idealist views of George Berkeley and Josiah Royce but especially William James's radical empiricism and, even more so, the phenomenalism of physicist Ernst Mach.

The main difference is that Whitehead conceives of the cosmos in terms of fundamental units of existence, instead of the inert atoms represented in the tradition of **Leucippus**, **Democritus**, and **Epicurus**. According to Whitehead's viewpoint, the ultimate atomic constituents of the Universe exist, like Leibnizian monads, as *processes* derived in relation to, and out of, the "now" of consciousness. But this is not to say that they are merely phenomenal or representational. As actual entities, that is, "actual occasions," they are not subject to the sort of mind–body problem as conceived in Cartesian dualism. The Universe according to Whitehead is one insubstantial substance that exists in a chaotic sort of Heraclitan perpetual flux. What immediately appears here and now is real; beyond that is nothing. The Universe, which exists without any static substances, must therefore be understood without the use of any static concepts typical of science and philosophy. The cosmos as a whole must be understood as an interconnected network of individually independent, but mutually complementary, *events*.

This revolutionary aspect of Whitehead's philosophy, though still poorly understood and not widely accepted today, was well ahead of its time. Events, as conceived by Whitehead, are themselves spatiotemporal unities; they exist as actual extensions, and they are what give rise from within the cosmic flux to individual organisms capable of being aware of themselves and of others. What we define as consciousness, he argues, consists of the relationships between events; and, more significantly, every entity consists of all its active relations with all others in a cosmic synchronicity. This Whitehead calls "prehensive occasion." And perhaps most significant of all, Whitehead's fundamental (*i. e.*, process) units of existence do not persist with identity over time. They have no permanent identity, and no history; they exist in a perpetual process of becoming. That is, the annihilation of one set of entities is, itself, the result of the creation of the Universe moving on to the next momentary birth in which each event loses its uniqueness, preserving thereby nothing but the flow of process.

The upshot of this rather extraordinary aspect of Whitehead's cosmology is that since the Universe exists in virtual flux, it cannot be completely understood: not ever, not by anyone. According to Whitehead, the single greatest error made by scientists and philosophers has been the mistaking of intellectual abstractions for actual entities, or what he calls "the fallacy of misplaced concreteness." Moreover, the truly permanent aspects of the Universe do not exist within the realm of *actuality* but only within the realm of *possibility*, and it is the possibilities themselves – not the momentary actualities – that constitute the "eternal objects" of the Universe. The virtual flux of creation and annihilation makes possible the existence of the Universe as a whole which, *necessarily*, is incomplete and unknowable, except as momentary influxes into the process of existence.

Anyone who recognizes in Whitehead's cosmic architecture certain similarities with quantum mechanics and quantum cosmology should not be surprised that he was singularly unimpressed with **Albert Einstein**'s general theory of relativity. He wrote:

> … in the 1880's … nearly everything was supposed to be known about physics that could be known – except a few spots, such as electromagnetic phenomena, which remained (or so it was thought) to be coordinated with the Newtonian principles. But, for the rest, physics was supposed to be nearly a closed subject. … By the middle of the 1890's there were a few tremors, a light shiver as of all not being quite secure, but no one sensed what was coming. By 1900 the Newtonian physics were demolished, done for! [This] had a profound effect on me; I have been fooled once, and I'll be damned if I'll be fooled again! … There is no more reason to suppose that Einstein's relativity is anything final, than Newton's *Principia*. The danger is dogmatic thought; it plays the devil with religion, and science is not immune from it.

Daniel Kolak

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Whitford, Albert Edward

Born **Milton, Wisconsin, USA, 22 October 1905**
Died **Madison, Wisconsin, USA, 28 March 2002**

American photometrist Albert Whitford coordinated the first of five (to date) decadal reports laying out the future course of astronomy in the United States (*Ground-Based Astronomy: A Ten-Year Program*, generally called the Whitford Report and published in 1964). He is also eponymized in the Stebbins–Whitford effect, which might have been early evidence for the evolution of galaxies with the age of the Universe but was in fact an error in allowing for the effects of stars with strong hydrogen features on the spectra of the galaxies of which they are a part. As director of the Lick Observatory, he was instrumental in bringing its 120-in. telescope project into successful operation.

Whitford received a BA in physics in 1926 at Milton College, with which his family had long-standing connections, and his Ph.D. in physics in 1932 at the University of Wisconsin for work under Charles Mendenhall and Julian Mack on a problem in atomic spectra. This problem required him to acquire skills in laboratory instrumentation including vacuum technology and the measurement of very small electric currents. Jobs in physics not being plentiful in 1932, Whitford gladly accepted an assistantship at the Wisconsin and Washburn Observatory under its then director, **Joel Stebbins,** who was attempting to improve the technology of photoelectric photometry with a potassium hydride cell and a quartz-fiber electrometer. Whitford succeeded in attaching a vacuum-tube amplifier to the cell and encasing both the photoelectric cell and the amplifier in a vacuum chamber to reduce noise from cosmic-ray ionization. He spent the years 1933–1935 on a National Research Council Fellowship at the California Institute of Technology and at the Mount Wilson Observatory, working still with Stebbins, who observed a good deal at Mount Wilson, and also working on atomic spectra with **Ira Bowen**. During this period, Whitford developed from an instrument builder to a full-fledged observer, learning photographic spectroscopy from **Alfred Joy** and observing the absorption and reddening of stars at the North Galactic Pole with Stebbins.

Whitford returned to Wisconsin in 1935, interrupting his tenure there from 1941 to 1946 for work on radar at the Massachusetts Institute of Technology under Lee DuBridge, pushing the technology to shorter wavelengths that could resolve, for instance, the periscope of U-boats. Whitford returned to the University of Wisconsin as an associate professor in 1946, where teaching duties required that he acquire the broad knowledge of astronomy that had not been part of his own student career but that so much characterized his work thereafter. Whitford succeeded Stebbins as director of Washburn in 1948 and continued to observe at the Mount Wilson Observatory and Lick Observatory on Mount Hamilton. In 1956, he persuaded the Wisconsin administration to provide funding for a 36-in. Cassegrain photometric telescope on a dark site outside the city, considerably improving both the research and teaching opportunities in Madison, but he left in 1958 to become director of the Lick Observatory. There, Whitford supervised the completion of the 120-in. reflector (then the second-largest telescope in the world after the 200-in. on the Palomar Mountain) and played an active role in the development of its cameras, drawing on the lab skills he had been developing all his life. Whitford also played an important role in the founding of what became the Kitt Peak National Observatory, available to all American astronomers on a scientifically competitive basis.

Through the years, Whitford continued to improve the techniques of photometry, extending the standard wavebands from purely visible light into the ultraviolet and infrared as far as the Earth's atmosphere would permit. He used this to observe distant, hot, bright stars and thus trace out both the distribution of dust in the Milky Way and the properties of the grains that make it up and redden starlight. The best known of his students at Wisconsin was the late Olin Eggen, also a photometrist. After resigning the Lick directorship in 1968, Whitford again took up active undergraduate and graduate teaching. His students from this period (including Jack Baldwin, David Burstein, Alan Dressler, and David Soderblom) and from his postretirement years (including Michael Rich and David Terdrup) have branched out into an enormous range of kinds of galactic, extragalactic, and stellar astronomy. Whitford's last major research effort focused on attempting to determine whether the stars in the central bulge of our own galaxy are as rich in heavy elements as those found in elliptical galaxies and large bulges.

Whitford was elected to the National Academy of Sciences (1954) and the American Academy of Arts and Sciences, received the Henry Norris Russell Lectureship of the American Astronomical Society, and the Bruce Medal of the Astronomical Society of the Pacific (1986 and 1996). He served the community as vice president (1965–1967) and president (1967–1970) of the American Astronomical Society.

Michael Rich

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Whiting, Sarah Frances

Born **Wyoming, New York, USA, 23 August 1846**
Died **Wilbraham, Massachusetts, USA, 12 September 1927**

With an abiding conviction that astronomy, in keeping with all science, should be taught as astronomy is done, in both laboratory and observatory settings, Sarah Whiting established the first such program in laboratory instruction for women in the United States at Wellesley College, and devoted her career to innovative teaching of astronomical principles and techniques. Whiting was one of two daughters of Elizabeth Lee Comstock Whiting and Joel Whiting. Sarah's father traced his American lineage back to a Mayflower passenger and other early settlers. He was a graduate of Hamilton College, and served successively as a teacher and a principal at several secondary-level academies in upper New York State. He guided Sarah's educational development during her childhood, tutoring her in Latin, Greek, and mathematics, as well as physical sciences, in all of which she was precocious. She often accompanied him to his school and helped him set up demonstrations for his "natural philosophy" classes.

This educational environment predisposed Sarah to seek her own career as a teacher. She attended Ingham University, a collegiate-level academy in Le Roy, New York, chartered in 1857 by the New York legislature to grant 4-year degrees to women. She received the AB degree in 1864, at the age of 18, and taught there initially. Employed subsequently at the Brooklyn Heights Seminary, a secondary school for girls, Whiting taught both classics and mathematics for approximately a decade.

Whiting's interests were not limited to those disciplines, however, and she frequently attended science lectures in New York City, many of them devoted to recent discoveries in astronomy, physics, photography, and spectroscopy. **Annie Cannon**'s obituary quoted Whiting: "I was really started on my scientific career by some lectures, brilliantly illustrated…. These had fascinated me with the application of the spectroscope to astronomy." A lecture on the 1869 solar eclipse furthered Whiting's interest in astronomy. In 1876, Henry Durant sought out Whiting for the faculty of Wellesley College, which he and his wife Pauline had founded the previous year for the express purpose of educating women. Durant specified that women would constitute the faculty and administration, including the president. Functioning as a trustee as well as a benefactor, Durant set the policy and developed a Wellesley curriculum in which science and mathematics were required disciplines on par with the humanities.

Durant was acquainted with **Edward Pickering** at the Massachusetts Institute of Technology [MIT]. Pickering established the first instructional physics laboratories in the United States. Following Pickering's example, Wellesley science courses incorporated a strong laboratory component. At Durant's request, Pickering allowed Whiting to study at MIT for 2 years as a guest, since women were not then admitted as students, to prepare herself for laboratory instruction in physics. From 1876 to 1878, Whiting taught mathematics at Wellesley while commuting to MIT 4 days a week. At MIT she studied the equipment as well as experimental procedures before ordering materials for her Wellesley laboratories.

In 1878, the fifth-floor attic of Wellesley's College Hall was adapted for use as a physics laboratory. Whiting showed a high degree of mechanical aptitude in the assembly, with Durant's assistance, of apparatus that had arrived in parts. She is credited with establishing the second undergraduate physics instructional laboratory program in the United States, the first for women.

After Whiting began teaching astronomy in 1879, she remained in contact with Pickering, who was by then director of the Harvard Observatory. She devised astronomical laboratory exercises that could be performed in daytime, to prepare for as well as supplement night observations. She taught astronomy for 20 years using only a 4-in. Browning portable telescope, a celestial globe, an ephemeris, photographs, and star charts.

Whiting was tireless at bringing phenomena to students and students to phenomena. Cannon, in the obituary she wrote for her former professor, commented, "She let no striking astronomical event pass without arousing the attention of the whole college," citing as examples a bright comet in 1882 (C/1882 R1) and, later that year, the transit of Venus. (In 1882, Cannon was a junior at Wellesley; in 1895 she returned to Wellesley as Whiting's teaching assistant.)

In 1898, Stephen V. C. White offered a 12-in. Fitz/Clark telescope for sale. Whiting had taken many of her Brooklyn Academy students to White's observatory to observe through this telescope and admired its optical quality. During a carefully planned dinner, Whiting impressed a wealthy Wellesley trustee, Mrs. John C. Whitin, with the college's need for an observatory. Whitin agreed to endow an observatory including the Fitz/Clark telescope. Dedicated in 1900, and expanded in 1906, the Whitin Observatory included a residence for Sarah Whiting, its first director. She shared the living quarters with her sister Elizabeth, an administrative employee of the college. The Whiting sisters were frequent and popular hostesses to students, alumnae, faculty, and college visitors at the observatory. Whiting was devoutly religious and strongly in favor of Prohibition, and in accord with the rigid expectations of her era, she remained unmarried.

In earlier years Whiting had expressed a feeling of stress for "being the only woman in places where women were not expected." Yet she was not deterred from her inquiries, visits, travels, and guest enrollments in advanced courses at both American and European institutions. Committed to the precept that good teaching arises from good knowledge, though she did no research herself throughout her career, Whiting vigilantly kept abreast of research results and instrumental innovations and kept her teaching updated. Whiting's curriculum in astronomy incorporated more physics than did other contemporaneous programs designed for women. Building on her experience in teaching both subjects, she included class and laboratory work on spectroscopy and photometry as well as instructional segments on variable stars and sunspots. Winifred Edgerton, the first woman to receive a Columbia Ph.D. in astronomy (1886), found that her undergraduate preparation in celestial mechanics under Whiting was at a level fully equivalent to graduate work at Columbia. By 1905, Wellesley was able to offer a master's degree in astronomy. Whiting used her sabbatical leaves for trips to Europe, during which she was welcomed at the laboratories of noted scientists, mostly in the British Isles but occasionally on the Continent. In 1896 she traveled to Scotland, where she studied in Edinburgh with Sir Peter Guthrie Tait.

Whiting spent extensive time with the astrophysical pioneers Sir **William Huggins** and Lady **Margaret Huggins**, noted for their work in stellar spectra, so it is not surprising that Whiting emphasized stellar spectroscopy in her teaching. She took special pleasure in her association with Lady Huggins. After the death of Sir William in 1910 Lady Huggins bequeathed astronomical equipment and artifacts from their Tulse Hill home and observatory to the Whitin Observatory. Whiting described these items in an article published in *Popular Astronomy*.

In 1912 Whiting relinquished her chairmanship in physics, but continued as director of the observatory until 1916. In anticipation of retirement, she mentored Louise McDowell, her former student in the class of 1898, who returned to Wellesley from Cornell in 1909 with a Ph.D. and an established record in physics research. McDowell became chairman of the physics department when Whiting stepped down. After retiring from the college in 1916, Sarah and Elizabeth moved to their final home in Wilbraham, Massachusetts. Sarah died of atherosclerosis and kidney disease.

A member of the American Astronomical Society and the American Physical Society, Whiting was honored for her innovative teaching at several stages of her career. In 1883 she was one of the first six women elected to fellow status in the American Association for the Advancement of Science, and the only one in astronomy or physics. In 1905, Tufts University awarded her an honorary Sc.D. degree.

Frieda A. Stahl

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Whitrow, Gerald James

Born **Kimmeridge, Dorset, England, 9 June 1912**
Died **London, England, 2 June 2000**

Gerald Whitrow published over 100 papers and many books, mostly on the subject of time.

Whitrow entered Christ Church, Oxford, graduating with a double first-class degree in 1933. He remained to carry out research with **Edward Milne** on kinematical relativity, and received his D.Phil. in 1939. Whitrow was a mathematics lecturer at Christ Church from 1936 until 1940, when he had to join the Ministry of Supply as a scientific officer doing war research. In 1945, he went to Imperial College, University of London, where he was successively an assistant lecturer and a lecturer in mathematics. Whitrow was promoted to reader in Applied Mathematics in 1951. In 1972 he received a personal chair in the History and Applications of Mathematics.

Perhaps the most important of Whitrow's books was *The Natural Philosophy of Time* (1960). He showed that time could be studied independently of its magnitude. Other books included *The Structure of the Universe* (1949) and (with H. Bondi, W. B. Bonnor, and **Raymond Lyttleton**) *Rival Theories of Cosmology* (1960). The latter was written at the time of the debate between the Big Bang and steady-state theories of the Universe. Whitrow's historical work included a paper on **Robert Hooke**.

Whitrow played an important part in many societies, libraries, and archives. He was president of both the British Society for the History of Science and the British Society for the Philosophy of Science, and was a founding member and first president of the British Society for the History of Mathematics.

Roy H. Garstang

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Widmanstätten, Aloys [Alois] Joseph Franz Xaver von

Born **Graz, (Austria), 13 July 1754**
Died **Vienna, (Austria), 10 June 1849**

Austrian printer and meteoriticist Aloys von Widmanstätten has his name firmly associated with the patterns of lines seen in iron and iron–nickel meteorites when they are sectioned and etched. The family traced its ancestry to Georg Widmanstätten, a devoted Catholic and successful printer in Bavaria. He was knighted in 1548 by Emperor Karl V. The noble name was transferred to Johann Andrea Karl Beckh, husband of Susanne Widmanstätten and granddaughter of Georg, because her brother Ferdinand, who was Mayor and City Judge of Graz, had no son to inherit the title.

Johann and Susanne von Widmanstätten were the parents of Aloys, and their printing business was successful until Johann died in 1765, leaving it to his 11-year-old son. Aloys studied natural science at the University of Graz and, in 1806, sold his inherited business and moved to Vienna.

In Vienna, Widmanstätten took over the position of director of the newly founded Imperial Technical Museum (Fabriksproduktenkabinetts). According to Dr. Heinrich Thurn, the present director of the museum, there are no photographs available of Aloys von Widmanstätten. He was told that Widmanstätten considered himself so ugly that he did not want to be photographed. Widmanstätten remained a bachelor all his life and died at his home in Vienna (Spiegelgasse 25) at the age of 95.

Widmanstätten was 11 years in the service of the Imperial palace, from 1806 to 1817. It was during this period that Emperor Franz (1768–1835) sent him in 1808 to study the meteorite that fell in 1751 at Agram (the present Zagreb, Croatia, at that time part of the Austrian Empire). This was a particularly auspicious time in meteoritics, because the witnessed falls of meteorites at Wold Cottage, Yorkshire, England (December 1795) and L'Aigle, France (April 1803) had finally convinced most of the European scholarly community that stones truly do fall from the sky.

Because of his printing background, Widmanstätten was used to experimenting with printer's ink. He polished the Agram meteorite, etched it, inked the surface, and made a print on paper. When he noted the characteristic pattern, he studied other meteorite samples in the collection. In 1810, Widmanstätten examined a Siberian specimen and a Mexican specimen sent to the emperor from Berlin by the German chemist Martin Klaproth (1743–1817). In 1812, he examined the large meteorite from Elbogen in Bohemia, and finally in 1815 he examined a piece of a Carpathian meteorite. It was his coworker and successor as the curator of the Meteorite Collection, Carl von Schreibers, who first published the prints as a supplement to a book on meteorites.

German physicist **Ernst Chladni** (1756–1827), who started the study of meteorites, visited Vienna in the spring of 1812 and witnessed the printing of meteoritic patterns. He included in his book *Feuer Meteore* (Vienna, 1819) a number of lithographed illustrations of whole and sectioned meteorites made directly from the etched surface. The Widmanstätten pattern was explained by the mineralogist Gustav Tschermak von Seysenegg (1836–1927) in Vienna.

Iron meteorites are pieces of once molten metallic cores in asteroids that were subsequently eroded and fragmented by impacts after slow cooling. Depending on their nickel content, they are classified into three categories: <6% Ni, 6–14% Ni, and >14% Ni. Iron meteorites containing 6–14% nickel are the most common. Besides their nickel content, iron meteorites are distinguished from other iron metallic finds by the typical Widmanstätten structure. The formation of such a pattern is characteristic of systems consisting of two solid metallic alloys of different composition – in the present case with low and high nickel contents, respectively – that have separated slowly from the molten state upon cooling. The presence of large crystals in iron meteorites is also regarded as evidence of slow changes occurring in the metal over a long period of time.

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Wildt, Rupert

Born **Munich, Germany, 25 June 1905**
Died **Orleans, Massachusetts, USA, 9 January 1976**

German–American theoretical astrophysicist Rupert Wildt solved a long-standing problem in the analysis of stellar atmospheres by recognizing that hydrogen atoms with an extra electron (H^- ions) play an essential role in controlling the flow of radiation through the outer layers of the Sun and other cool stars. The son of Gero and Hertha Wildt, he received a Ph.D. in 1927 from the University of Berlin with a thesis on color photography. His first positions were at the Observatory of Bonn (1928–1929) and the University of Göttingen (1930–1935).

In 1931, while at the University of Göttingen as part of the group headed by **Hans Kienle**, Wildt recognized that broad absorption features in the spectra of the giant planets, which had been discovered nearly 10 years earlier by **Vesto Slipher**, were produced by molecules of methane and ammonia absorbing in higher harmonics. This was confirmed by **Theodore Dunham** at the Mount Wilson Observatory soon after. Wildt immigrated to the United States in 1935, holding positions at the Mount Wilson Observatory (1935–1956 as a Rockefeller Fellow), Harvard University (visiting lecturer 1936), the Institute for Advanced Study and Princeton University (1936–1942), and the University of Virginia (assistant professor, 1942–1946). His tenure at Virginia was interrupted by war service (1944–1946) with the Office of Scientific Research and Development.

Wildt's best-known discovery was made at Princeton and published in 1939. Work by **Edward Milne** in the 1920s had established that in order to understand the light we see coming from the Sun and other cool stars it was necessary to postulate that the atmospheric gases were more opaque to light between about 4,000 and 9,000 Å than could be accounted for by adding up all the lines and ionization edges of known atoms and ions. Wildt identified the missing opacity source as H^-, hydrogen atoms with an extra electron attached just tightly enough that a 9,000 Å photon can remove it. The source of the extra electrons was necessarily metal atoms, accounting for the extra redness of metal-rich stars.

Yale University offered Wildt an assistant professorship in 1947, and he moved up to associate professor in 1949, professor in 1958, and acting department chair (1966–1968). He remained there until his retirement in 1973, apart from visiting professorships at Hamburg (1951), the National University of Mexico (1963), the universities of California, Berkeley (1956), and Göttingen (really an honorary professorship emeritus from 1960). When Yale joined the Association of Universities for Research in Astronomy [AURA] (which operated the national observatories at Kitt Peak and Cerro Tololo), Wildt became its representative on the board and was president of AURA from 1965 to 1968 and from 1971 to 1972, and chairman of the AURA board from 1972 almost until his death.

As early as 1938, Wildt had concluded that Jupiter and the other giant planets must have hydrogen as their most abundant element, probably hydrogen in the solid state (which has not yet quite been observed on Earth). His Yale student, Wendell DeMarcus, completed a 1951 thesis on the internal structure of Jupiter, based on the assumption that its chemical composition was the same as that of the Sun, which is roughly right, and that most of the hydrogen would be solid, which is still under discussion. Wildt's best-known Yale student is probably the planetary system dynamicist Myron Lecar of Harvard. Late in his career, Wildt studied the flash (chromospheric) spectrum of the Sun, attempting to use the maximum height at which various lines can be seen to map out coronal temperature and density. He also, before 1957, embarked on an effort to calculate the atmospheres of stars without making the assumption called Local Thermodynamic Equilibrium [LTE] (roughly, the assumption that the radiation field can be described by the same temperature as the kinetic energy of the atoms). That non-LTE calculations are essential is now universally recognized, though Wildt's work is not much cited.

Recognition on the whole came late. Wildt received the Bronze Medal of the University of Liège in 1962 and the Eddington Medal of the Royal Astronomical Society (London) 1966 for his work on H^-, and felt that his discovery of methane and ammonia in the giant planets had not received adequate credit. He was survived by his wife, the former Katherine Eldridge, and their two children.

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Wilhelm IV

Born **Kassel, (Hessen, Germany), 24 June 1532**
Died **Kassel, (Hessen, Germany), 20 August 1592**

Wilhelm IV built the first observatory in modern Europe with excellent instruments and staff, producing superior stellar catalogs. Wilhelm was the son of the Landgrave Philipp of Hessen (called the Magnaminous), who introduced the Reformation into Hesse and who became the leader of the Protestant princes. Wilhelm first obtained an education from private tutors at the court of Kassel, as well as, during the year 1546/1547, at the Gymnasium in Strasbourg founded by Johann Sturm. Already in childhood, he developed remarkable intellectual capabilities.

His interests in astronomy appeared to awaken early and were influenced by **Peter Apian**'s brilliant work, *Astronomicum Caesareum* (1540). Under the influence of this book, Wilhelm's interests developed in two directions. First, his fascination with the graphic modeling of revolving disks as a representation of the movement of stars (volvelles) led later to Wilhelm's contracting Eberhard Baldewein to build a planetary clock with a mechanism that is equally a work of art and a milestone in clock making. Wilhelm later had **Jost Bürgi** construct self-moving globes for him.

Wilhelm's second interest was in finding the precise locations of stars that were listed in the catalogs of his time. His first catalog, containing the locations of 58 stars observed with a torquetum, was the result of work during 1560–1563. He later refused to use a torquetum because its overhanging part did not provide enough stability. Observations during 1567/1568 resulted in a second catalog of 58 stars. This time the positions measured directly by Wilhelm himself were compared with those in contemporary catalogs. Both catalogs demonstrated an accuracy that is a clear advance over available star catalogs and represents an early example of the systematic observation of heavenly bodies.

Besides these observations, Wilhelm's systematic measurements of the locations of the Sun began in 1559, along with the observations of comets in 1558 and 1577, and the supernova of 1572 (SN B Cas) – to mention just a few of his publications. In addition to the large torquetum, Wilhelm used a wooden quadrant, as well as a carefully constructed metal azimuth quadrant. For these and other relatively large instruments, he erected a special structure at the Kassel palace as the first permanent observatory in modern Europe. When Wilhelm had to assume the regency of the Hesse–Kassel landgraviate after his father's death in 1567, only sporadic amounts of his time remained for astronomy. At times during the previous period, Wilhelm had brought scholars to his court to support him in his work. From around 1558, Andreas Schöner, son of **Johannes Schöner**, stayed in Kassel and was interested in both the early observations and the calculations involved in the planetary clock built by Baldewein and others. Baldewin also manufactured various observational instruments, such as a precision operating clock (the so-called minute clock), and participated in the observations. In addition to other observers at his observatory, Wilhelm collaborated with Victorinus Schönfeld, professor of mathematics in Marburg, and also held counsel, upon special occasions, with scholars such as **Caspar Peucer** (on the occasion of the supernova in 1572). In April 1575, **Tycho Brahe** visited the Kassel Observatory and received important support for his "Uranienburg," a facility soon to be built on Hven Island. By means of a diplomatic mission, Wilhelm arranged for support from the Danish king for Brahe's project.

On 25 July1579, Bürgi acquired his position as the landgrave's clock maker. Bürgi, coming from the Toggenburg region of Switzerland, constructed an excellent observational clock with a precision of movement unknown until then. With this device and with changes to the scales and instrument's sight settings, Bürgi, in collaboration with **Christoph Rothman** (who was working in Kassel around 1585), provided a remarkable improvement in the accuracy of the observations undertaken in Kassel.

Wilhelm recognized the need to compile a star catalog based on his own precise observations, to be used as the foundation for a reformed astronomy, one that took planetary motion into account when plotting the positions of planets alongside those of stars. The resulting star catalog was finally constructed on the basis of Rothmann's observations and represented, with its precise positions, a new quality in fixing the locations of stars. The reform of astronomy would, after Wilhelm, proceed on the basis of **Nicolaus Copernicus**' heliocentric system, Wilhelm being one of the first scholars to adopt it.

Already at the time of his observations of the supernova in 1572, Wilhelm concluded, on account of the absence of a possible parallax for this star, that it could not be found in the region below the Moon but in the realm of the stars. This realization was, along with Brahe's observations, one of the first indications that stars were mutable, a possibility that contradicted the principles of Aristotelian physics. Wilhelm further clarified this premise, especially during the appearance of the 1585 comet (C/1585 T1).

In the discussions surrounding Pope Gregory XIII's calendar reform, Wilhelm occupied a central position among the Protestant princes. He was involved in an exchange of opinions focusing above all on the fact that the reform should be rejected if it was merely an attempt to combine Catholic and Protestant church doctrine.

In all the work undertaken at the Kassel Observatory, Wilhelm proved himself not only to be accurately informed but always in the position to devise concrete observational tasks. Even in his extensive correspondence with Brahe, Wilhelm always appears as an astronomer of equal standing.

Important records of Wilhelm's observations can be found in the Kassel State Library, including the star catalogs from 1559 to 1563 and from 1566 to 1567. His scientific correspondence is currently found in the Hessen State Archives in Marburg and in the Saxon Main State Archives in Dresden.

Jürgen Hamel

Alternate name

Landgrave of Hessen-Kassel

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Wilkins, Hugh Percival

Born **Carmarthen, Wales, 4 December 1896**
Died **Bexleyheath, (London), England, 23 January 1960**

As an amateur astronomer, Hugh Percival Wilkins, as he was known, specialized in selenography and was a leading visual observer of the Moon in the middle of the 20th century. Wilkins was educated at Carmarthen Grammar School. He early on showed a marked aptitude for mechanics, and after service in the British Army during World War I, became a practical engineer in Llanelly, South Wales. He married in 1931, and subsequently moved to Kent, in the south of England, settling first in Barnehurst, then after World War II in Bexleyheath. Wilkins gave up practical engineering in 1941 and joined the Ministry of Supply. He remained a government official until 1959, when he retired with the intention of devoting the rest of his life to astronomical research. Within days, though, he suffered a heart attack. In spite of confident hopes of a full recovery, he had a relapse and died soon afterward.

Though deeply interested in geology, Wilkins's chief passion was astronomy. This developed early and led first to youthful experiments in telescope making and mirror grinding. Around 1909, Wilkins took up serious observation, notably of the planets, with the telescope he had made. His passion was so intense that he took a small spyglass with him into the trenches during the war.

His main preoccupation, however, was mapping the Moon, especially its then poorly known limb regions. In this respect, he was following a long tradition of outstanding British amateur lunar observers including **William Birt**, **Edmund Nevill**, **Thomas Elger**, and **Walter Goodacre**. Wilkins produced three maps of the visible hemisphere. He published his first map to a scale of 60 in. to the Moon's diameter in 1924. A second, 100 in. in diameter, was completed in 1932, and a third, of 300-in. diameter, appeared in 1946. The latter was revised for a third edition in 1951, and yet another revision was issued in 1954. Even so, he still was dissatisfied, and at the time of his death yet another map was planned.

Sadly, Wilkins's enthusiasm for the subject outweighed his abilities as a cartographer. His maps, which represent a prodigious effort, testify to his industry and dedication, yet are so crowded and unreliable as to be of historical interest only.

In 1946 the Lunar Section of the British Astronomical Association [BAA] was virtually moribund. Wilkins was entrusted with its reinvigoration. Ten years later, when he resigned his directorship, it had been transformed into a useful and enthusiastic organization with over 100 participating observers. The BAA Lunar Section served as a model for the burgeoning US-based Association of Lunar and Planetary Observers, and similar groups across the world. Following his resignation, Wilkins founded the International Lunar Society, becoming its first president and then its director of research. He also served on the council of the British Interplanetary Society.

Wilkins was an excellent lecturer, and broadcast frequently on radio and television. He also undertook a lecture tour of North America. Wilkins produced several books on popular astronomy, and contributed chapters and essays to multiauthored works. In recognition of his contributions to astronomy, the University of Barcelona conferred an honorary doctorate upon him in 1953.

Richard Baum

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Wilkins, John

Born **Fawsley, Northamptonshire, England, 1614**
Died **Chester, England, 16 November 1672**

John Wilkins's popular astronomical works, *The Discovery of a World in the Moone* (1638) and *A Discourse Concerning a New Planet* (1640), appearing when Wilkins was only in his mid-20s, became "the most influential English defense of Copernican astronomy in the second half of the 17th century." Though not scientifically original, they transmitted the insights and the excitement of **Galileo Galilei** and **Johannes Kepler** to a vernacular English readership in an engaging, speculative style that laid the foundation for the genre of science fiction.

Wilkins received a classical education at Oxford in the school of Edward Sylvester and was such an outstanding student that he matriculated at Oxford University in 1627, at the age of 13. After receiving his BA in 1631 he became a clergyman and served, among other roles, as warden of Wadham College (1648–1659), master of Trinity College, Cambridge (1659–1660), and Bishop of Chester (1668–1672). Wilkins's theological position was unclear, but he was sufficiently adaptable ecclesiastically and politically to flourish both before and after the Restoration (May 1660). In 1656 Wilkins married Robina French, the widowed youngest sister of Oliver Cromwell.

Wilkins chaired the November 1660 meeting of the newly founded Royal Society at which it was resolved to petition King Charles II for a charter. Wilkins's lifelong sociable encouragement of science earned him praise as "a great preserver and promoter of experimental philosophy."

Before Wilkins's publication of *The Discovery*, serious popular attention to or even awareness of the Copernican model in England was rare. For this reason, Wilkins was careful in introducing the most shocking, counterintuitive tenet of Copernicanism, namely, that the Earth moves and is therefore a "new planet." Although the main focus of *The Discovery* is lunar, Wilkins explicitly draws the inference of "other worlds" theory that follows from Copernican cosmology: If the Earth is a planet, then perhaps the planets (including the Moon) may be conceived to be Earths.

The Discovery strove to overcome resistance to Copernicanism that results from literalistic interpretation of certain passages of Scripture, from the sheer novelty of the idea of a moving Earth, and from traditional notions regarding the physical uniqueness and mutability of the Earth, in contrast to the pristine realms beyond. This work's main inspiration at the imaginative level appears to be Kepler's posthumous *Somnium* (1634). At the physical level, however, it hews closely to Galilei's *Sidereus Nuncius*. Thus Wilkins demonstrates the Earth-like, mountainous character of the Moon, and offers a similarly Galilean account of how both objects reflect the Sun's light mutually.

This simultaneous poetic and physical domestication of the Moon then opens the way to its being imagined as another world, another place of habitation (not in the older dominant sense of "world" as universe).

Moreover, if light may travel from Earth to the Moon, so perhaps can other things. In the revised edition of *The Discovery* in 1640, Wilkins suggested how "our posterity" might "find out a conveyance to this other world." The possibility, and difficulty, of space flight led Wilkins to speculate on the nature of gravity. For the difficulty seemed less if, as Wilkins argued, that "natural vigour whereby the earth does attract dense bodies unto it, is less efficacious at a distance." An account of precisely how much less this "natural vigour" grows with distance was offered later by **Isaac Newton**. But Wilkins's both imaginative and practical struggle to conceptualize human space travel helped to place the issue of gravity squarely on the agenda of physical theory.

A further problem for space travel that Wilkins helped to remove from the popular imagination was the idea of the crystalline spheres, which post-Copernican developments of astronomical thinking in both **Tycho Brahe** and Kepler had already effectively eliminated from scientific consideration. Robert Burton, in his contemporary *The Anatomy of Melancholy*, saw clearly what the solid spheres' removal implied for possible human exploration: "If the heavens then be penetrable, … it were not amiss in this aerial progress to make wings and fly up." Following Galilei, Wilkins treated "the heavens or stars" as "of a material substance." And he built into this physical approach to astronomy a satirical denial of the materiality – indeed the reality – of the supposed crystalline spheres, "this astronomical fiction," as he called them.

Wilkins offered his vernacular audience touches of satire, patient logical and arithmetical refutation of objections against Copernicanism, simple diagrams and explanations, unwavering piety, and undeniable poetic and rhetorical charm. For his countrymen, these qualities combined to diminish the strangeness of the new astronomy and to open its vistas in a moderate, unthreatening way. Wilkins thus contributed to both a buffering and a kindling of the spirit of science, as well as of science fiction. He articulated, in a word, new scientific and cosmic prospects.

Wilkins's impact also extended to other literatures beyond English. Both *The Discovery* and *A Discourse* were translated into French by Jean de la Montagne under the title *Le monde dans la lune* (Rouen, 1656). This edition is said in part to have inspired Cyrano de Bergerac's *Histoire comique des états et empires de la Lune*, 1656, and, most influentially, **Bernard de Fontenelle**'s *Entretiens sur la pluralité des mondes*, 1686. It is probable too that Wilkins helped stimulate the "other worlds" speculations of **Christiaan Huygens**, whose *Cosmotheoros* was published in Latin in 1698 and translated into English in the same year under the title *The Celestial Worlds Discover'd*. Wilkins's first German translator was **Johann Doppelmayer**, whose edition appeared in 1713 as *Johannis Wilkins … Vertheidigter Copernicus, oder, Curioser und gründlicher Beweiss der copernicanischen Grundsätze*.

Dennis Danielson

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William of [Guillaume de] Conches

Born **Conches, (Eure), France, *circa* 1100**
Died ***circa* 1154**

William was a philosopher, theologian, and astronomer, who published a survey of contemporary astronomical knowledge in the 12th century. He studied in Chartres, where he was a pupil of Bernard at Chartres (Bernardus Carnotensis). Later he was a teacher at Chartres and Paris, and he acted as Bernard's successor, whose school at Chartres he represented. From 1144 to 1149 William lived in the court of Geoffroi le Bel, and at the end of his life he found refuge in the court of the Duke Geoffroi V. Plantagenet. William also worked as a tutor of Geoffroi's son Henri II, future duke of Normandy and future king of England.

Interested in natural science, cosmology, and philosophical questions, William belongs among the early scholars who examined the biblical cosmological opinions not only from the traditional "literary" approach of exegesis of the Holy Scriptures, but also from the "scientific" point of view. For example, he refused the interpretation of the Venerable **Bede** and others on "supracelestial waters."

William's main work, Encyclopaedia *Philosophia Mundi*, contains among other things a survey of contemporary astronomical knowledge. It was published as a work of *Honorius Augustodunensis* (*Honorius von Autun*) in PL 172, and as a work of Beda Venerabilis in PL 90. Among William's other works, the dialogue *Dragmaticon philosophiae* (edited Strassburg, 1567; reprinted Frankfurt, 1967) stands out. He wrote the following commentaries: on **Boethius**' *De consolatione philosophiae*, on **Macrobius**' *Commentarii in Somnium Scipionis*, and on **Plato**'s *Timaios* (edited E. Jeauneau, *Glossae super Platonem*, Paris, 1965). His commentary on **Martianus Capella**'s *Encyclopaedia of Septem Artes Liberales* (the seven liberal arts) contains a basic knowledge of the later *trivium* and *quadrivium*, including astronomy. The glosses on Iuvenalis are perhaps also written by him (edited B. Wilson, Paris, 1980).

Alena Hadravová and *Petr Hadrava*

Alternate name

Guilelmus de Conchis

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William of Moerbeke

Born **Brabant, (Belgium), *circa* 1215**
Died **Corinth, (Greece), *circa* 1286**

William of Moerbeke translated **Aristotle** and **Archimedes** to Latin from Greek (as opposed to Arabic).

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William of [Guillaume de] Saint-Cloud

Flourished **Saint-Cloud, France, *circa* 1290**

Virtually nothing is known about calendricist William of Saint-Cloud's life other than the fact that he lived in Saint-Cloud, France, around 1290. Knowledge of his existence appears to stem largely from a report he gave (possibly more than one, as he is known for two different discoveries around the same time) in an almanac published in about 1290. William was probably a part of the School of Paris – Saint-Cloud is very close to Paris – and was most likely associated with the Church in some way.

William of Saint-Cloud is known for two significant discoveries, both dating from roughly the same time (possibly both reported in the same almanac in 1290). The first item that he discussed is the impairment of the eyes while viewing eclipses for too long. The eclipse in question is that of 4 June 1285. (Some reports indicate 5 June, but this is erroneous.) The manuscript, which was dated 5 years later, reported some observers experiencing near blindness for several hours or even several days in some cases. William followed the observational report by suggesting the use of a *camera obscura* – essentially the pinhole projection method still used today to safely view an eclipse. He also reported on the power lenses and mirrors.

William's other great accomplishment, around the same time, was his calculation of the obliquity of the ecliptic and the time of the vernal equinox from the Sun's position at the solstice. His observations brought out the inaccuracies in the Tables of Toledo developed by **Zārqalī**.

Ian T. Durham

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Williams, Arthur Stanley

Born **Brighton, (East Sussex), England, 1861**
Died **Feock, Cornwall, England, 1938**

Stanley Williams was one of the notable English amateurs in the late 19th and early 20th centuries who collectively established much of our knowledge about Jupiter's atmospheric dynamics. Specifically, Williams invented the terminology that has been adopted universally to describe the Jovian atmospheric zones and belts. He also perfected the technique for making central-meridian transit timings of various features within those belts to determine rotation periods and drift rates. His work firmly established the existence of stable atmospheric currents in various latitudes. Williams also discovered a number of variable stars and determined useful light curves and periods for many of these stars.

Unfortunately, little seems to be known of Williams's family, early life, and education. Professionally he was a solicitor, though he retired at an early age to devote his life to astronomy.

Although most of Williams's astronomical observations were made with a Calver equatorial reflecting telescope of only 6.5-in. aperture, he was able to see and recognize spots on Jupiter that others would have found difficult even with larger telescopes. He pioneered a method of measuring the longitudes (and hence drift rates) of Jovian spots by visually timing transits. His method of eye-estimates brought a withering attack from **George Hough**, who championed micrometer measurements of longitudes. The two had a robust argument about the relative merits of these techniques in the pages of the *Monthly Notices of the Royal Astronomical Society* in 1904 and 1905. In spite of Hough's attack, Williams and the other British amateurs continued making visual transit timings. Their work reliably established the pattern of atmospheric currents on Jupiter that is now known to be permanent. It is undoubtedly true that Hough's micrometer methods produced more accurate individual measurements of Jovian longitudes. Nevertheless, such measures were time-consuming and could not be applied to the large number of smaller and fainter objects observed productively by the British amateurs because the micrometer wires obscured these objects. The method of visual central-meridian transit timings remained a staple technique of planetary observation throughout the twentieth century.

Williams's own very detailed reports for 1880 were published privately as *Zenographical Fragments* volumes I and II. In the *Monthly Notices* in 1896 he reviewed all observations to date and made the first systematic listing of nine atmospheric currents on Jupiter.

In his analysis of colors on Jupiter, Williams combined his own observations (of over nearly 50 years from 1878 to 1936) with historical research. He argued that there was a periodic alternation in color between the major equatorial belts. However, like many proposed periodicities on Jupiter, his theory failed to hold up over a longer epoch.

Williams's other major astronomical activity was observing variable stars. While on a visit to Australia in 1885/1886, he engaged in systematic visual photometry of the brighter stars in the southern skies, eventually publishing his results as *A Catalogue of the Magnitudes of 1081 Stars Lying between -30° Declination and the South Pole*. In the course of his extended study, Williams detected the variability of V Puppis with a period of 1.45 days, the first of his many discoveries and period determinations for variable stars. Williams was the first British astronomer to use photography in searching for variable stars beginning in 1899. He was only able to continue this work for about 4 years because of ill health; after World War I he could not afford the cost of photographic plates. At a time when relatively few variable stars were known, Williams discovered over 50 variables, including the irregular variable RX Andromedae, Y Lyrae, Y Aurigae, YZ Aurigae, and the very short-period eclipsing binary WY Tauri.

Williams's photographic search for variable stars produced one other result of great importance by chance. A plate exposed for 1 hour and 16 min on the night of 20 February 1901 covered the area in which **Thomas Anderson** discovered Nova Persei 1901 at magnitude 2.7 only 28 hours later. Williams's plate did not contain an image of Nova Persei, confirming that the nova had brightened enormously in the intervening period. Williams later made important observations of Nova Persei 1901.

Williams was born near the sea and had always been a keen sailor. In 1920 he won the Challenge Cup for what was then a notable single-handed voyage to Vigo, Spain, and back. In his retirement he lived on a barge in Cornwall with his observatory on the shore nearby. His last Jupiter observation was a month before his death. In 1923, the Royal Astronomical Society awarded Williams its Jackson-Gwilt Medal recognizing his contributions to both planetary and variable star astronomy.

John Rogers and *Roy H. Garstang*

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Williams, Evan Gwyn

Born **London, England, 13 October 1905**
Died **Pretoria, South Africa, 31 May 1940**

Though he showed considerable early promise in stellar spectroscopy, Gwyn Williams's career was cut tragically short by complications arising from surgery in 1940. The elder son of Christopher Williams, an artist and portrait painter, Williams was educated at the Froebel Educational Institute School, London, England, and the King Alfred School, Hampstead, London, England. He played cricket and hockey and was active in the Boy Scout movement. In 1924 Williams entered Trinity College at the University of Cambridge where he studied natural sciences. He continued to play hockey but joined several student societies including the University Mountaineering Club, chess club, and Cambridge Photographic Club. After graduating in 1927 Williams continued his astronomical studies at University College, London, until 1928 when he also became a fellow of the Royal Astronomical Society.

Williams left London for Cambridge in 1928 where he worked at the Solar Physics Observatory. In 1929, he obtained an Isaac Newton Studentship and was granted a Commonwealth Fund Fellowship in 1931. The fellowship enabled him to study for 2 years at the California Institute of Technology and the Mount Wilson Observatory. His work was primarily on B type stars, whose spectrum predominantly contains absorption lines of hydrogen and neutral helium. On Williams's return from the United States, he continued at Cambridge as an Isaac Newton Student until 1936 when he again obtained an assistant position at the Solar Physics Observatory.

In his stellar spectrophotometry, Williams measured absorption-line intensities and developed a classification system for B type stars. He made a special study of the spectra from Nova Herculis 1934. In 1936 Williams traveled to Omsk in Siberia, USSR, where he successfully identified new lines in the Paschen series of hydrogen from the solar corona during a total solar eclipse.

After his marriage to Fiona Lauder in April 1937, Williams became first junior observer at the Radcliffe Observatory in Pretoria, South Africa. Originally founded in Oxford, England, in the late 18th century, the observatory had been managed by the trustees of the Radcliffe estate. In the early 1930s, the trustees took the imaginative, and at the time controversial, decision to move the observatory to South Africa and furnish it with a 74-in. reflector. The large telescope would be invaluable for studies of the distant and highly luminous stars of types O and B in the southern Milky Way. The importance of those stars to theories of stellar evolution was already understood, and Williams was emerging as an expert in this area.

The turret and the telescope mounting were well advanced in South Africa by 1938, but work on the primary mirror was delayed in England by the onset of war in September 1939. In the interim, Williams devoted himself to three-color photometry of B type stars, Cepheid variables, and other objects of interest using the 7-in. finder for the large telescope. Williams's sudden death from complications following emergency surgery was a great loss to the Radcliffe Observatory. It was only after the war in 1948 that the 74-in. mirror was installed and the telescope placed in productive service by **David Evans**.

Williams wrote over 20 astronomical articles, published mainly in the *The Monthly Notices of the Royal Astronomical Society*. His early death was a great loss to astronomy.

David W. Dewhirst and *Mark Hurn*

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Wilsing, Johannes Moritz Daniel

Born **Berlin, (Germany), 8 September 1856**
Died **Potsdam, Germany, 23 December 1943**

Germany astronomer Johannes Wilsing was an early spectrophotometrist. The son of Eduard Wilsing and Clara Hitzig Wilsing, he studied at Göttingen and received his doctorate from the University of Berlin. Wilsing joined the Astrophysical Observatory in Potsdam in 1881, was promoted to observer in 1893 and chief observer in 1898, and retired from Potsdam in 1921.

Before 1900, Wilsing worked on the rotational period of the Sun (trying to explain the variation with latitude), on the density of the Earth, on the parallax of the star 61 Cygni (one of the first ever measured, by **Friedrich Bessel**, in 1838), and on the classification of stellar spectra. In 1896, together with **Julius Scheiner**, Wilsing attempted to detect radio emission from the Sun. They failed because the equipment was not sensitive enough; such emission was not seen until the work of **James Hey** during World War II. Later, Wilsing's work included spectrophotometric observations of stars, and, together with Scheiner and (later) W. Munch, the determination of the effective temperatures of 109 stars. In 1907/1908, Wilsing and Scheiner extended their spectroscopic work to determine the composition of the surface of the Moon. Further work covered the determination of the diameters of stars from their colors and brightnesses, the laws of blackbody radiation, and investigations of refractor objectives with **Johannes Hartmann**.

A lunar crater is named for Wilsing.

Christof A. Plicht

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Wilson, Albert George

Born **Houston, Texas, USA, 28 July 1918**

Albert Wilson exposed and located dwarf galaxies on more than 1,000 Palomar Observatory Sky Survey [POSS] plates. Wilson succeeded **Vesto Slipher** as director of the Lowell Observatory.

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Wilson, Alexander

Born **Saint Andrews, Scotland, 1714**
Died **Edinburgh, Scotland, 16 October 1786**

Alexander Wilson suggested that stars may be prevented from falling together under mutual gravitational attraction by their motion around a distant common center of gravity, but he is best known today for his observation that sunspots at the limb of the visible surface of the Sun appear to be saucer-shaped indentations, known as the Wilson effect.

Wilson was the younger son of Patrick and Clara (*née* Fairfoul) Wilson. His father, the town clerk of Saint Andrews, Scotland, died when he was comparatively young, leaving Alexander to be raised primarily by his mother. After graduation with an MA from Saint Andrews University in 1733, he apprenticed to a surgeon and apothecary in Glasgow and then moved to London to take charge of an apothecary's shop. In 1742, Wilson conceived of a new method of casting printer's type and returned to Saint Andrews where he established a typefoundry. In 1744 he moved the enlarged typefoundry to near Glasgow, and provided type for Mssrs. Foulis, printers of University of Glasgow publications, especially for their editions of the Greek classics. Wilson married Jean Sharp in 1752.

As a person of rather broad experimental interests and interested in astronomy since he was a student, Wilson began making reflecting telescopes in the late 1740s. In 1756, Glasgow University received a legacy of valuable astronomical instruments from Dr. A. Macfarlane of Jamaica, and built an observatory to house these instruments. In 1760 King George II appointed Wilson as the first professor of practical astronomy and observer at the University of Glasgow. Wilson published several astronomical papers in the *Philosophical Transactions of the Royal Society* dealing with the 1769 transit of Venus, the eclipses of Jupiter's first satellite, and the cross-wires in eyepieces.

Wilson's best-known paper, which dealt with the nature of sunspots and what became known as the Wilson effect, appeared in the *Philosophical Transactions* in 1774. The paper was based on his observations of a very large sunspot in November 1769. Wilson noticed that just before the Sun's rotation carried the spot beyond the Sun's limb, the apparent width of the penumbra on the side of the spot remote from the limb was less than that on the side closest to the limb. When the spot later reappeared on the other limb of the Sun, the narrowing of the penumbra was obvious on the opposite side of the spot, but the spot regained its usual appearance as it moved away from the limb. Although this effect had been remarked upon by such earlier observers as **Christoph Scheiner**, **Philippe de la Hire**, **Jacques Cassini**, Leonard Rost of Nuremberg, and Pastor Schülen of Essingen, Wilson was the first to analyze the observation in a geometrical sense. He accounted for the observed saucer shape of the spot as an effect of perspective. He extended his reasoning to make a novel interpretation of the nature of the Sun. Arguing that the Sun was a dark body surrounded by a luminous atmosphere, Wilson suggested that sunspots might be funnel-shaped holes in the Sun's atmosphere, and that the umbra of the sunspot was the hole at the bottom of the funnel near the surface of the darker solid body. Although **Joseph de Lalande** challenged Wilson's description, the idea was supported by **William Herschel** and was only displaced by spectroscopic studies a century later.

Reacting to **Isaac Newton**'s question as to why the stars do not all fall together under the force of their gravity, Wilson suggested that this might be because they are in periodic rotation around some distant center of gravitation. A letter conveying this speculation was acknowledged by William Herschel in the latter's paper on the structure of the Universe.

Wilson was interested in the variation of the temperature with altitude in the Earth's atmosphere, which he studied using thermometers mounted on kites. He also worked on methods of determining the specific gravity of liquids and solids. Wilson resigned his position in 1784, and his second son, Patrick, succeeded him as a professor. One of the founders of the Royal Society of Edinburgh, Wilson received a Gold Medal from the Royal Danish Academy, and an honorary MD degree from Saint Andrews University. A lunar crater is named for him.

Roy H. Garstang

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Wilson, Herbert Couper

Born **Lewiston, Minnesota, USA, 28 October 1858**
Died **Northfield, Minnesota, USA, 9 March 1940**

Herbert Couper Wilson enjoyed a long and successful career as a teacher, administrator, and editor of two important journals in American astronomy.

Wilson's long relationship with Carleton College began at age 14, when he entered the Carleton Preparatory Department, eventually matriculating to the college itself at age 17. A successful student of mathematics and astronomy under **William Payne**, Wilson served for a year as principal at a public school in Jaynesville, Minnesota, after receiving his B.A. from Carleton in 1879. He then returned to astronomy as a graduate student at the University of Cincinnati under **Ormand Stone.** Wilson served as *astronomer pro tempore* in charge of the Cincinnati Observatory until 1884 when **Jermain Porter** arrived to replace Stone. In 1886, Wilson earned the first Ph.D. granted by Cincinnati for "six faithful years of work" on double stars, comets, and asteroids. During his work at Cincinnati, Wilson met and married Mary B. Nichols. They had three daughters and one son, **Ralph Elmer Wilson**; Ralph would earn a Ph.D. in astronomy and serve professionally at the Lick and Mount Wilson observatories.

After completing his work at Cincinnati, Wilson worked as a computer for the Transit of Venus Commission at the US Naval Observatory in Washington, while he unsuccessfully sought positions at the Washburn Observatory, University of Wisconsin, and the Lick Observatory, University of California. In the fall of 1887, he joined the faculty at Carleton as associate professor and stayed there for the remainder of his career.

At the time of his return, Payne was still publishing *The Sidereal Messenger*, and Wilson became a frequent contributor to that journal. When Payne and **George Hale** joined forces to publish *Astronomy & Astro-Physics*, Wilson became an associate editor of that journal. He remained in that capacity when Payne stopped publishing *Astronomy & Astro-Physics* and introduced a new journal, *Popular Astronomy*, the third astronomical journal to be published at Carleton College under his editorship. When Payne retired in 1909, Wilson became the editor of *Popular Astronomy* and continued in that capacity until his own retirement in 1926.

Wilson was a favorite teacher on campus, particularly well known for his lanternslide lecture on a "Trip to the Moon." He organized the Carleton Observatory's first off-campus expedition in 1889 to view and photograph a total solar eclipse in California. Wilson developed his expertise with cameras while a student at the Lookout Mountain Observatory in Cincinnati. His plates of nebulae, planets, and variable stars were often requested by other astronomers for study and illustration, especially his photograph of nebulosity surrounding stars in the Pleiades cluster. Wilson founded the *Publications of the Goodsell Observatory*, in which some of his photos of nebulae, sunspots, asteroids, and the spectra of the Sun's corona are presented.

Wilson served as the Carleton College dean of faculty as well as chairman of the Mathematics and Astronomy Department for many years, and shared responsibility, as a member of a committee of three, for the general administration of the college during a 2-year period in which the college was without a president.

Thomas R. Williams

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Wilson, Latimer James

Born **Nashville, Tennessee, USA, 1 December 1878**
Died **Nashville, Tennessee, USA, 17 May 1948**

Latimer Wilson excelled as an amateur planetary observer, producing excellent sketches and photographs over a career that spanned four decades. His mother had described the thrill of looking through telescopes with the youthful **Edward Barnard** at the Vanderbilt University Observatory to her young son while introducing him to the night skies. In 1908, Wilson took up astronomy with a homemade refractor using a single 4-in. lens; he fashioned a 10-in. Newtonian reflector in 1910, and in 1912 completed the 12-in. Newtonian reflector that was to be his primary instrument for the remainder of his life.

By 1913 the quality of Wilson's planetary sketches attracted the attention of a young Frederick Charles Leonard (1896–1960), who appointed Wilson director of the Society for Practical Astronomy's [SPA] Planetary Section. At the 1915 meeting of the society at the University of Chicago, Wilson was elected president of the SPA. With **Forrest Moulton** and George N. Saegmueller of Bausch and Lomb, Wilson planned for the third annual SPA meeting which was to be held in Rochester, New York. However, the society collapsed when World War I diverted interest from astronomy and financial pressures arose after Leonard matriculated at the University of Chicago and his parents dropped their support of the society.

Wilson continued to observe, sketching and photographing the planets, especially Mars, and publishing his results from time to time in *The English Mechanic*, *Knowledge*, and *Popular Astronomy*. His observing interests expanded to include meteors; **Charles Olivier** appointed him a regional director for the American Meteor Society. Wilson joined the American Astronomical Society at the invitation of **Philip Fox**, and soon thereafter was made a member of the Sociétié Astronomique de France by **Nicholas Flammarion**. From 1919 to 1922 Wilson was employed as an editor by *Popular Science Magazine*, and for a time in the 1930s he served as the director of the Chattanooga Observatory. In 1935 Wilson became a member of the Amateur Astronomers Association of America [AAAA]; his observations were accorded much discussion in their journal *Amateur Astronomy* by AAAA Planetary Section director, Edwin P. Martz (1918–1966). Through Martz, Wilson's observations were included in **Gérard de Vaucouleurs**' published works on Mars. Wilson's careful observation detected bright flashes in the southern polar cap of Mars on 30 May 1937, a phenomenon also observed in 1890 by **Percival Lowell** and **William Pickering**, and in 2001 by a number of members of the Association of Lunar and Planetary Observers.

Thomas R. Williams

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Wilson, Olin Chaddock, Jr.

Born **San Francisco, California, USA, 13 January 1909**
Died **West Lafayette, Indiana, USA, 14 July 1994**

American stellar spectroscopist Olin Chaddock Wilson, Jr. – the suffix disappeared in the 1940s – discovered the first set of stellar activity cycles analogous to the solar sunspot cycle and is eponymized in the Wilson–Bappu effect, a correlation between the absolute brightness of cool stars and the strength of the emission-line cores in strong absorption lines due to hydrogen and calcium.

By the time Wilson earned the BA degree in physics from the University of California, Berkeley, in 1930, the 60-in. telescope no longer stood as the largest in the world: It had been surpassed by the mighty 100-in. Hooker telescope on Mount Wilson, which saw first light on 2 November 1917.

Wilson received the first Ph.D. awarded in astronomy by the California Institute of Technology, in 1934, for work on a comparison of the Paschen and Balmer series of hydrogen lines in stellar spectra, done with **Paul Merrill** (the paper appearing as Merrill and Wilson). Wilson had been hired as assistant astronomer at the Mount Wilson Observatory on 1 July 1931, but was not related to Benjamin "Don Benito" Wilson, after whom the mountain is named. His thesis observations rested on spectrograms from the 100-in. telescope. Wilson detailed the shapes of higher principle quantum number members of the Balmer and Paschen series in luminous A and B-spectral type stars, including the emission lines of P Cygni and γ Cassiopeia.

Wilson became a full staff astronomer at the Mount Wilson Observatory in 1936. Working generally at bright lunar phase between the great dark-phase observations of **Edwin Hubble** and **Milton Humason**, Wilson continued to illuminate stellar phenomena through spectra obtained with the 100-in. telescope. Wilson studied Wolf–Rayet objects, and discovered the first binary member of its class. He investigated the expansion of planetary nebulae, atmospheric inhomogeneities in the cool supergiant, ζ Aurigae, and radial velocities of interstellar neutral sodium and singly ionized calcium lines.

Wilson spent the war years working with Charles Lauritsen on the California Institute of Technology rocket project, where he met a fellow worker named Katherine Johnson. They married in 1943.

With M. K. V. Bappu, Wilson found that the width of the chromospheric emission cores of the singly ionized calcium H and K Fraunhofer lines in a cool star accurately marks its luminosity. Wilson also found that the intensity of the H and K emission cores decreases with age, and later greatly extended that conclusion in collaboration with Sir **Richard van der Riet Woolley**.

The hallmark of chromospheric activity on the Sun is its 11-year periodicity. Wilson was struck in the 1930s by the **George Hale**–**Seth Nicholson** work on calcium K-line spectroheliograms showing that the solar cycle was prominent in disk-averaged calcium emission. Wilson hypothesized that the fluxes of the H and K emission cores of other lower main-sequence stars, whose disks were unresolved, might display measurable variations similar to the solar cycle. Wilson early obtained spectrograms at the 100-in. telescope; after World War II he revisited the project only to conclude that photographic plates were too insensitive to record the subtle cycles.

By 1966 a more-sensitive photometric system at the 100-in. telescope encouraged Wilson to survey approximately 100 stars on or near the lower main sequence. With monthly measurements accumulated over 10 years, Wilson discovered that stellar chromospheric activity includes the property of interannual variation. Three patterns are observed in lower main-sequence stars: *cyclic*, with a period of several years to a decade, resembling the solar cycle; *variable*, with either multiple periods or nonperiodic variability; and *flat*, with no measurable variability. In general, stars with highly variable records are relatively young, while the cyclic and flat records may be two different phases of centuries-long variability, as recorded for the Sun, for example, in comparing the present, pronounced cycle of the Sun to its phase of diminished variability during the Maunder minimum (*circa* 1640–1720).

After Wilson reached compulsory retirement age in 1974, the activity-cycle project continued under Arthur Vaughn, who had constructed the chromospheric spectrograph for it, and is now in its 36th year of recording chromospheric variations in lower main-sequence stars under the leadership of the author of this sketch. At Wilson's prompting, the survey now includes evolved stars.

Wilson was awarded the Russell Lectureship of the American Astronomical Society in 1977 – his lecture dealt with stellar cycles – and the Bruce Medal of the Astronomical Society of the Pacific in 1984. He served as president of the Astronomical Society of the Pacific in the 1950s.

A monument erected in Wilson's memory is found on the southeastern side of the 100-in. telescope dome on Mount Wilson.

Sallie Baliunas

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Wilson, Ralph Elmer

Born **Cincinnati, Ohio, USA, 14 April 1886**
Died **Corona del Mar, California, USA, 25 March 1960**

American observational astronomer Ralph E. Wilson made his greatest impact with an extensive catalog of radial velocities published in 1953 after his retirement. Wilson's catalog remained useful into the modern era of precision stellar measurements. He was the son of **Herbert Wilson**, long-term director of the Goodsell Observatory of Carleton College in Northfield, Minnesota, and received his AB from Carleton College in 1906. His Ph.D. came in 1910 from the University of Virginia for a thesis on positions of stars in the Orion Nebula. After a year as acting director at Goodsell, he was appointed assistant astronomer at the Lick Observatory from 1911 to 1913, where he worked on **William Campbell**'s bright-star radial-velocity program. Following this, Wilson spent the next 5 years as assistant astronomer at Lick Observatory's Southern Station in Santiago, Chile. Employing the 36-in. reflector there, he pursued a similar project on the radial velocities of bright stars. He later extended this research to include radial velocities of planetary nebulae in the Magellanic Clouds. After obtaining the necessary spectrograms, Wilson found that their radial velocities were high, leading him to suspect that the Magellanic Clouds might be external to the Galaxy and could be closely connected with the spiral galaxies.

Following war service in 1918 as an aeronautical engineer with the Bureau of Aircraft Production, Wilson transferred to the Dudley Observatory in Albany, New York, where he remained for the next 20 years. Wilson's work included fundamental studies of the Galaxy in general and also star clusters, principally by meridianal proper-motion measurements. His results helped to delineate the motion of the Sun through the Galaxy. Wilson carried out early investigations on the rotation of the Galaxy and the Sun's galactocentric distance.

It was at the Dudley Observatory that Wilson completed the five-volume *General Catalogue of 33,342 Stars* initiated by **Benjamin Boss**. This catalog also remained useful for many decades. The Carnegie Institution was gradually transferring its support for astronomy from the Dudley Observatory to Mount Wilson, and Ralph Wilson moved there in 1938, retiring in 1951. The agreement of names is a coincidence but must have prompted a good deal of joking.

While at Dudley in the early 1920s, Wilson had conducted a vigorous investigation into the zero-point of the period–luminosity [PL] relation of Cepheid variables. After moving to the Mount Wilson Observatory in 1938, he revisited this problem by combining proper-motion and radial-velocity measurements to investigate the space motions of different types of stellar objects, in particular red variables and long-period variables, deriving an independent value for the zero-point of the Cepheid PL relationship. Wilson's photographic PL curve and zero-point essentially confirmed **Harlow Shapley**'s values. However, research published by **Edwin Hubble** in 1932 indicated that the absolute magnitudes derived for the globular clusters in the Andromeda nebula were on average about 1.5 magnitudes too faint in comparison with their galactic counterparts.

The problem with the galactic and extragalactic distance scales had two pieces. First, Shapley had neglected the possibility of interstellar absorption of starlight by dust. This was discovered in 1930 by **Robert Trumpler** but not incorporated into redetermination of the distance scales until after World War II. Second, it turns out that there are two kinds of Cepheid variables associated with young and old stars, with the young ones being about twice as bright (1.5 magnitudes) as the latter. The two had been confused, making it seem as if external galaxies, based on the young Cepheids in their disks, were much closer than they really were – and would have been found to be if it had been possible to observe the old Cepheids in their globular clusters. This was not fully sorted out until 1952 when **Walter Baade** announced, and **David Thackeray** immediately confirmed, an approximate doubling of all distances outside the Milky Way. Further expansions occurred later, and Shapley's scale inside the Milky Way eventually proved to be somewhat too large.

Wilson's retirement from the Mount Wilson Observatory in May 1951 was marked by a session at a meeting of the Astronomical Society of the Pacific on "The Radial-Velocity Programs of the Pacific Coast Observatories," featuring a contribution by Wilson himself. Concluding an exemplary scientific career, Wilson published his famous *General Catalogue of Stellar Radial Velocities* in 1953.

Wilson's other achievements included serving as editor and associate editor of *Popular Astronomy* (1910–1914), associate editor of the *Astronomical Journal* (1929–1949), and president of the Astronomical Society of the Pacific (1946). He received a Gold Medal from the Danish Academy in 1926 and was a member of the US National Academy of Sciences.

Ralph Wilson died after a protracted illness and was survived by his wife Mary Adelaide (*née* Macdonald) and their son, Herbert Ralph.

John McFarland

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Wing, Vincent

Born **North Luffenham, (Leicestershire), England, 19 April 1619**

Died **North Luffenham, (Leicestershire), England, 30 September 1668**

Vincent Wing was a surveyor, an astrologer, an almanac compiler, and a prolific writer of astronomical works. Wing, whose father was a small landowner, was apparently self-educated, having learned at an early age, by his own exertions, some Latin, Greek, and mathematics. He lived throughout his life in or near North Luffenham.

Wing's first publication was an *Almanack* (1641) that included solar-eclipse data computed for English coordinates for the years 1641 to 1654. His *Urania Practica* (1649), written with the assistance of William Leybourn, was the first English book to describe the fundamental principles of computational astronomy and provided tables for calculating the times of lunar and solar eclipses. Based on **Philip Lansbergen**'s *Tabulae motuum coelestium perpetuae* (1632), and Ptolemaic in spirit, the book was criticized for various alleged errors by the English astronomer **Jeremy Shakerley** in the latter's *The Anatomy of Urania Practica* (1649) and quickly defended by Wing in his own *Ens fictum Shakerlaei: or the Annihilation of Mr. Jeremie Shakerley, His In-artificial Anatomy of Urania Practica* (1649).

In his *Harmonicum Coeleste: Or the Coelestial Harmony of the Visible World* (1651), Wing added tables to calculate the positions of the planets Mercury, Venus, Mars, Jupiter, and Saturn. From these tables he derived *An Ephemerides of the Coelestiall Motions for 1652 to 1658* (1652). The dispute with Shakerley may have influenced Wing's conversion to Copernicanism, which was evident in his *Astronomia Britannica* (1652). Wing published revised planetary tables in his *Astronomia instaurata: Or a New and Comprehensive Restauration of Astronomy* (1656), from which he derived *An Ephemerides of the Coelestiall Motions* for 1659 to 1671 (1658). Wing's two sets of *Ephemerides*, in the view of **John Flamsteed**, were the "exactest" to be had during this period. In the last few years of his life Wing was engaged in a heated dispute with the English astronomer **Thomas Streete** regarding the accuracy of the latter's *Astronomia Carolina* (1661); the disagreement centered on the magnitude of the horizontal parallax of the Sun.

Wing's annual almanac, *Olympia Domata*, had sales averaging 50,000 copies per year, and it was continued by various family descendants until 1805. Wing also published *Geodates Practicus: Or the Art of Surveying* (1664).

Craig B. Waff

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Winlock, Joseph

Born **Shelby County, Kentucky, USA, 6 February 1826**

Died **Cambridge, Massachusetts, USA, 11 June 1875**

Joseph Winlock, a mathematical astronomer, was twice superintendent of the *American Ephemeris* before becoming the third director of the Harvard College Observatory. There he upgraded the observatory's equipment, expanded its research programs into the New Astronomy of astrophysics, and invented the photoheliograph.

Winlock's grandfather, a surveyor, participated in the convention that framed Kentucky's constitution, and both his grandfather and father had distinguished military careers during the War of 1812. Winlock was educated in his home state. His mathematical prowess was so evident that immediately upon his graduation from Shelby College in 1845, he was offered an appointment there as professor of mathematics and astronomy. Winlock spent his first savings on a set of the *Astronomische Nachrichten*, then the world's foremost astronomical journal; to gain enough fluency to read it, he arose daily before dawn to speak German with a laborer on his father's farm.

By all accounts, Winlock was rescued from frontier obscurity by attending the fifth meeting of the American Association for the Advancement of Science, held in Cincinnati, Ohio, in 1851, where he met Harvard astronomer and mathematician **Benjamin Peirce**. That contact led in 1852 to Winlock's joining the corps of calculators for the *American Ephemeris and Nautical Almanac*, which was then headquartered in Cambridge, Massachusetts. He remained there for 5 years, meeting and marrying Isabel Lane (1856), from whom he eventually had six children.

In 1857, Winlock was appointed professor of mathematics at the US Naval Observatory in Washington. The next year, however, he was made superintendent of the *Ephemeris and Almanac*, and returned to Cambridge. In 1859, he became head of the mathematical department of the US Naval Academy in Annapolis, Maryland. But when the Civil War removed the academy to Newport, Rhode Island in 1861, Winlock returned to Cambridge and his old superintendent's position. Over his intermittent 11 year service with the ephemeris office, he became known for his carefully prepared tables of Mercury, and was one of the original founding members of the National Academy of Sciences (1863). In 1866, Winlock made his last move – this time locally within Cambridge – to become director of the Harvard College Observatory and Philips Professor of Astronomy; 2 years later, he concurrently became professor of geodesy at Harvard's Lawrence and Mining Schools.

Winlock inherited an institution with aging equipment, small endowment, inadequate staff, and a huge backlog of unpublished raw observations from his two predecessors, father and son astronomers **William Bond** and **George Bond**. As director, Winlock made it his priorities to modernize the instrumentation, get the massive research of the Bonds into print, and turn the observatory into an efficient research center with a secure financial base. In so doing, Winlock revealed significant talent as an inventor, fund-raiser, and administrator.

Because the observatory's original meridian circle had suffered damage during its transportation from Europe, the main 15-in. Merz and Mahler refractor was often pressed into service as a substitute. To free the great telescope for more suitable research, Winlock solicited more than $12,000 in donations to purchase a brand new meridian circle; the new circle, mounted in 1870, was customized to his own specifications (among them shortening the piers and sealing the bearings from dust under glass) – improvements adopted by later observatories. Under his 9-year directorship, the observatory also acquired an auxiliary 7-ft. Clark equatorial, a number of clocks and chronometers, a Russian "broken" transit, self-recording meteorological instruments, and several spectroscopes. These last Winlock acquired to expand Harvard College Observatory's research beyond traditional positional astronomy and into the fledgling field of astrophysics; he himself used the spectroscopes during total solar eclipses to study the solar corona.

Winlock also proved to be an optical innovator. In 1869, Winlock led an expedition to Kentucky to observe the total solar eclipse of 7 August. Determined to photograph the Sun's corona – something not yet captured on film – Winlock rejected the then-standard method of eyepiece projection, instead placing the photographic plates at his telescope lens's prime focus. Although his images were thus very small – the Sun's disk was only 0.75 in. in diameter – Winlock's photographs not only revealed the corona, but also showed that it extended farther from the Sun than astronomers had realized. To attain larger images at the total solar eclipse on 22 December 1870 in Spain, Winlock invented a horizontal telescope using a lens 4 in. in diameter having a focal length of 40 ft. The telescope lens, a heliostat (an unsilvered plane mirror for reflecting the Sun into the lens), and camera were mounted on separate piers; daylight was excluded by a tube disconnected from them all. Winlock's design pioneered what later became known as a photoheliograph – a very long horizontal telescope that served as the centerpiece of many late-19th-century eclipse expeditions. (Some later astronomers contested his priority.) From 1870 on, Winlock's 4-in. horizontal telescope was used for daily solar observations as well as for photographing the transit of Venus in 1874.

When Winlock took over the Harvard Observatory, its annual operating budget was $200, a sum meager even in its time. For the eclipse of 1869, to stretch an additional $500 allocated by the Harvard Corporation for his 10-man expedition, Winlock pioneered the method of requesting free rail transportation for astronomical observers and equipment. In 1871, he followed the lead of **Samuel Langley**, director of the Allegheny Observatory in Pittsburgh, Pennsylvania, and began charging for the accurate time signals the Harvard Observatory had been telegraphing for free to New England railroads, jewelers, hotel managers, and other customers. By 1875, the observatory's average annual income from the time service was about $2,400 (and later peaked at about $3,000).

Winlock died of a mysterious illness quite unexpectedly. A man unusually laconic in conversation, he also wrote unusually few papers. Both his untimely death and his emphasis in publishing his predecessors' zone catalogs of stars, solar drawings, and aurora observations in the *Annals of the Astronomical Observatory of Harvard College* resulted in much of his own research not being printed during his lifetime. Thus today, Winlock's original early contributions to astronomical photography, photometry, and spectroscopy are less recognized than his faithful stewardship of the Harvard College Observatory.

Trudy E. Bell

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Winnecke, Friedrich August Theodor

Born **Gross-Heere near Hildesheim, (Niedersachsen, Germany), 5 February 1835**
Died **Strasbourg, (Bas-Rhin, France), 2 December 1897**

August Winnecke was an outstanding observational astronomer. He was the son of the local clergyman, Heinrich F. L. Winnecke (1803–1852), and his wife Dorette (*née* Quensell), who died some days after giving birth to August. Two aunts, sisters of his father, took care of the household and the child for the first 5 years. In 1840 the father retired and sent his son first to school in Gittelde, where relatives accommodated him. Later, August was sent to Hoya to attend high school and moved to Hanover in 1850 to prepare for university, which he started in 1853 at Göttingen, studying astronomy.

This science had fascinated Winnecke since he had moved to Hanover, where he used a small telescope for his first observations. In Göttingen he replaced this instrument with a 3-in. comet seeker, made by the workshop of Merz in Munich. During his observations in a garden, Winnecke met a young high-school pupil who later would also be a well-known astronomer: **Arthur Auwers**. **Carl Gauss**, who had given up lecturing due to his age, helped Winnecke with his studies and even sent his first papers to the *Astronomische Nachrichten* to have them published.

In the fall of 1854 Winnecke moved to Berlin for further studies. Several letters, published in the *Astronomische Nachrichten* during the following 2 years, show that he was active during night and day, either at the telescope or at the table reducing the observations he had made. Here he also discovered his first comet C/1854 Y1 (Winnecke–Dien). In later years he found 12 more comets, 5 of them as codiscoverer. On 7 August 1856 Winnecke received his doctorate with a thesis *de stella η Coronae borealis duplici*, which he dedicated to **Johann Encke**.

After finishing his studies in Berlin, Winnecke moved to Bonn to work with **Friedrich Argelander**. Here he extended his knowledge of practical astronomy, reflected in his published papers in the *Astronomical Nachrichten*, Volumes 45–48. His main subjects were the 6-in. heliometer, which he tested thoroughly, and parallax observations on the star Lalande 21185 and a planetary nebula with the aforementioned instrument. In addition he acquired positional data for the stars of the Praesepe cluster.

In the fall of 1857 **Friedrich Struve** visited Bonn and met Winnecke, whom he invited to work at the well-equipped main observatory in Pulkovo, Russia. Winnecke accepted and arrived there in July 1858. His observations between September 1858 and October 1864, made with the meridian circle manufactured by Repsold, represent the majority of the data for the first Pulkovo catalog of stars. Another major work was the observations of Mars during the 1868 opposition, executed by several observatories worldwide, which were based on a suggestion by Winnecke and led to an improved value for the solar parallax as given by Encke 40 years earlier. Here one of Winnecke's favorite sayings bore fruit: "Man muss an allem Zweifeln" (One has to question everything).

Additional work included observations of comet C/1858 L1 (Donati) with the 7-in. heliometer and, together with **Otto W. Struve** and Frederico A. Oom, the total solar eclipse on 18 July 1860 in Spain. Winnecke got acquainted with Sir **George Airy** on that occasion and met him again in Greenwich in 1864, where Winnecke was sent to test **James Bradley**'s instruments. Winnecke's papers, published again in the *Astronomische Nachrichten*, Volumes 49–66, report of his widespread interests, such as observing comets, nebulae, and variable stars.

Winnecke was soon promoted to elder astronomer and then to Vice Director. Soon after his marriage to Otto Struve's niece, Hedwig Dell, in May 1864, he had to take care of the director's duties when Otto Struve fell ill. Winnecke himself became ill in the fall of the same year. This and the stress of these additional duties may have led to a mental illness from which he did not recover easily. So he resigned from his post in December 1865 and went to Bonn, seeking the help of a Dr. Hertz. Winnecke recovered within a year and moved to Karlsruhe, Germany, where the climate was much milder than in Pulkovo.

He started observing again, first with his old comet seeker and then with a 5-in. instrument made by Reinfelder and Hertel. The collection of instruments was extended when Winnecke received the Berlin heliometer for further tests in preparation for the upcoming Venus transit in 1874. During the 5 years in Karlsruhe, he found four comets and observed mainly variable stars. In 1869 he was elected to the board of the Astronomische Gesellschaft and held that post for 12 years.

In 1872 Winnecke was invited to build an observatory at the new University of Strasbourg. His tasks there included, besides constructing and supervising the erection of the new buildings (which were completed in 1880), observing nebulae at the old observatory and teaching at the university. In addition he led the preparations for the expeditions to observe the Venus transit and computed a lot of the results. The new 18-in. refractor arrived in 14 crates on 6 August and was tested by Winnecke and erected by Repsold between 6 and 30 November. On 21 November Winnecke celebrated the move to his new home in Strasbourg with his wife, two sons, and three daughters.

On 13 January 1881, in the weeks when the equipment of the observatory was moved to the new buildings, Winnecke's son Fritz had a fatal accident on a frozen lake. After a while Winnecke returned to work, but suffered from a relapse of his mental illness a year later. Before he moved again to Bonn in February 1882 to seek help, he was offered the post of professor in Munich to succeed **John Lamont**. Instead he stayed in Strasbourg, where he was elected headmaster in the early weeks of 1882. Winnecke never recovered. He was buried in Strasbourg.

Numerous comets (including 7P/Pons–Winnecke) bear his name, and minor planet (207) Hedda was named in honor of Winnecke's wife.

Christof A. Plicht

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Winthrop, John

Born **Boston, Massachusetts, (USA), 19 December 1714**
Died **Cambridge, Massachusetts, USA, 3 May 1779**

More than any other colonial, John Winthrop was responsible for transplanting Newtonian physics to the American colonies. Winthrop was one of 16 children born to Adam and Anne Winthrop. He was educated at the Boston Latin School and then at Harvard College, where he graduated in 1732. In 1738, he was appointed as the second Hollis Professor of Mathematics and Natural Philosophy at Harvard, succeeding Isaac Greenword. Winthop held this position until his death. He married Rebecca Townsend in 1746, and then 3 years after her death in 1756, Winthrop married the widow Hannah Fayerweather, who survived him. In 1766, he was elected as a fellow of the Royal Society and 3 years later, he became a member of the American Philosophical Society. Winthrop received honorary LL.D. degrees both from the University of Edinburgh (1771) and from Harvard (1773). He was the great-grandnephew of his namesake, John Winthrop. The earlier Winthrop was one of the founding members of the Royal Society of London and Governor of Connecticut from 1660 until his death in 1676.

Along with his Yale College contemporary Thomas Clap, Winthrop is given credit for first introducing Newtonian physics and calculus to college students in the English colonies. Winthrop had charge of Harvard's collection of scientific instruments, and after a disastrous fire on 24 January 1764, he set about replenishing the collection with the help of his family's influential friends, including John Hancock and Benjamin Franklin. More than a dozen of his scientific publications appeared in the *Philosophical Transactions of the Royal Society* and covered such topics as earthquakes, weather, the Mercury transits of 1740, 1743, and 1769, the return of comet 1P/1758 Y1 (Halley), and the Venus transits of 1761 and 1769. With regard to earthquakes, he attributed the effects to a wave of the Earth with vertical and horizontal components. He used the Mercury transit observations to help determine the longitude difference between Greenwich, England, and Cambridge, Massachusetts. The Venus transit observations were part of an international campaign to determine the solar parallax and hence the absolute scale of the Solar System. Winthrop successfully observed the Venus transit of 6 June 1761 from Saint John's, Newfoundland, the only useful set of observations from North America. From Cambridge, Massachusetts, he also observed the Venus transit of 3 June 1769. Winthrop's two lectures on the return of comet 1P/Halley showed that he was abreast of the ideas on comets presented by **Edmond Halley** and **Isaac Newton**.

Donald K. Yeomans

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Wirtanen, Carl Alvar

Born **Kenosha, Wisconsin, USA, 11 November 1910**
Died **Santa Cruz, California, USA, 7 March 1990**

Carl Wirtanen was noted for the carefulness and dedication to his work across a long astronomical career and is remembered for the Shane-Wirtanen counts of galaxies.

Wirtanen completed his undergraduate (B.S: 1936) and graduate (A.M: 1939) degrees at the University of Virginia and majored in astronomy, mathematics, and physics. Until 1941, he worked at the Leander McCormick Observatory of the University of Virginia, where he derived stellar distances from their trigonometric parallaxes. In October 1941, Wirtanen became an observing assistant at the Lick Observatory of the University of California. During World War II, he took part in ballistics research at the Naval Ordnance Test Station at China Lake, California.

In October 1946, Wirtanen returned to the Lick Observatory. For the next 32 years, he acted as an observer and research assistant in conjunction with the observatory's 51-cm Carnegie astrograph, a specialized photographic survey telescope. Like other Lick astronomers, Wirtanen lived on Mount Hamilton (with his wife, Edith, and their son and daughter) until the Lick staff moved their offices to the new Santa Cruz campus in 1966. He retired in 1978.

Wirtanen's major astronomical contributions were centered on programs using the Carnegie astrograph. This survey telescope was conceived by **William Wright** to measure the proper motions of the stars in our Galaxy by using background galaxies as the reference frame. Proper motions are the small angular displacements of stars that can only be detected by comparing photographs taken at widely separated epochs. The Lick Observatory proper-motion program was one of the first to determine "absolute" proper motions of stars, relative to the reference frame provided by some 50,000 faint galaxies. The program involved photographing a major part of the sky (north of declination −33°) in 1,246 exposures between 1947 and 1954. The work was shared equally between Wirtanen and Lick Observatory director **Charles Shane**. Wirtanen also participated in taking the plates during the second epoch (1968–1978) under the direction of Stanislavs Vasilevskis; he was the only astronomer involved in both epochs.

The first results (*Lick Northern Proper Motion Program: NPM1 Catalog*) for 149,000 stars in fields outside the Milky Way were published in 1993. The final catalog (*NPM2*), which includes 232,000 stars within the Milky Way fields, was published in 2004.

Starting in the 1950s, Shane and Wirtanen, independently and in duplicate, counted the number of galaxies in each of the 1.6 million fields on the proper-motion survey plates. Previously, galaxy counts had only been possible on the small fields obtained with large reflectors, or else were derived from inhomogeneous survey data. The Shane–Wirtanen counts first revealed the clustered distribution of galaxies over the entire northern sky, based on a homogeneous sample. These counts have been a valuable tool for astronomers. Twenty years later, they were used for correlation analysis and they provide information on galaxy distribution that is still of interest.

While studying the Lick survey plates, Wirtanen found five comets. In recognition of his discovery of the first four comets, he received the Donohue Comet Medal Awards of the Astronomical Society of the Pacific. One of these (46P/1948 A1) is of particular interest. Perturbations by Jupiter have changed this comet's orbit to one with a period of 5.46 years and a perihelion distance of 1.06 AU, making it accessible to investigation by spacecraft. The European Space Agency's International Rosetta Mission was originally expected to rendezvous within a kilometer of the nucleus of comet 46 P/Wirtanen in 2011. Unfortunately, the launch of this spacecraft was delayed so that another target had to be selected.

Wirtanen also discovered numerous minor planets. Two of these, (1965) Toro and (29075) 1950 DA, are on orbits that bring them unusually close to the Earth, making them useful for detailed observation; (29075) is of further interest because its rotation period (2.1 hours) is the second fastest known for its size. About the time of Wirtanen's retirement, the minor planet (2044) Wirt was named in his honor, employing the name by which he was generally known to family and colleagues alike.

During the 1960s, Wirtanen was closely involved with Thomas D. Kinman in a program with the astrograph to discover RR Lyrae variables. These variable stars have characteristic short periods and may be recognized at great distances. This program showed that the halo of our Galaxy (of which these variables are tracers) was more extended than previously thought. Besides taking plates for this survey, Wirtanen played the crucial role of "blinking" (or comparing) the plates to discover the variables.

A bibliography of Wirtanen's publications may be found in the Mary Lea Shane Archives of the Lick Observatory, Santa Cruz, California.

Thomas D. Kinman

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Wirtz, Carl Wilhelm

Born **Krefeld, (Nordrhein-Westfalen), Germany, 24 August 1876**
Died **Kiel, Germany, 18 February 1939**

Carl Wirtz, the astronomer, measured magnitudes and positions of nebulae, and made many observations of Solar System objects. He was among the first to study the redshift-magnitude and redshift-diameter diagrams of nebulae (galaxies), which is why Allan Sandage, the pupil and successor of **Edwin Hubble**, called Wirtz "the European Hubble without telescope."

Wirtz studied astronomy at Bonn University (1895–1898). After that he served as an assistant at the Wien-Ottakrieg Observatory (1899–1901), as a lecturer in the Hamburg School of Navigation (1901–1902), and as an astronomer–observer and professor at the Strasbourg Observatory (1901–1915). In 1905 he married Helene Borchardt. He served in the German army (1916–1918). In 1919 Wirtz was appointed as an extraordinary professor of the Kiel Observatory, and in the years 1934–1936 he served as the director of that observatory.

The last years of Wirtz' life were obscured by the political situation in Germany. Mrs. Wirtz was of Jewish origin, and under the Nazi regime the whole family fell into disgrace. In 1937 Carl Wirtz lost the right to teach.

At the Bonn Observatory, Wirtz measured the declinations of 487 stars. At the Strasbourg Observatory he participated in the observations of magnitudes and positions of 1,257 nebulae, and in data reduction. At Strasbourg, Wirtz also made observations of asteroids and planets. His observations of many comets are valuable, especially the long series of magnitude estimations. During the Kiel period Wirtz was one of the first astronomers to work in the field of extragalactic astronomy.

In his 1922 paper "A Note Concerning the Radial Motion of Spiral Nebulae," Wirtz put forward the first correlation between redshift (velocity) and distance (as determined from apparent magnitudes) that was roughly linear. Like the correlation published in 1929 by Hubble, it was based on velocities measured by **Vesto Slipher**. A diagram of velocities versus apparent diameters (another distance indicator) followed in 1924, along with a plot of the surface brightnesses of galaxies versus their diameters, and, in 1926 he published a luminosity function for galaxies. Because the distance indicators used by Wirtz were not as reliable as Hubble's Cepheid variables, his correlations were less tight and were not seen by the community as of great importance.

At the Fifth General Assembly of the International Astronomical Union in 1935, Wirtz presented the project "An Extragalactic Reference Frame for Stellar Proper Motion Measurements."

In 1912 Wirtz won the Lalande Prize of the Paris Academy, and he was honored by having a Martian crater named for him.

Mihkel Joeveer

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Witt, Carl Gustav

Born **Berlin, (Germany), 29 October 1866**
Died **Falkensee near Berlin, Germany, 3 January 1946**

Carl Witt discovered the minor planet (433) Eros, which makes relatively close approaches to the Earth.

Witt was born as the son of a teamster. In 1887, he passed the graduate examination of the Andreas-Realgymnasium (Berlin). For the next three years, Witt studied mathematics and physics at the University of Berlin, where he came under the influence of astronomers Friedrich Tietjen and Wilhelm Julius Foerster. But thereafter, Witt was offered a stenographer's position attached to the Reichstag (Germany's democratically elected Parliament). This occupation provided Witt's means of employment for many years; he gradually advanced to the head of the stenographer's bureau.

But Witt never lost his desire to become an astronomer, and increasingly devoted his spare time to studies of the heavens, especially minor planet and comet observations, which were aided by the development of astrophotography. On 13/14 August 1898, Witt exposed a photographic plate using the 12-in. telescope at the students' Urania Observatory that recorded the trail of a minor planet whose rapid motion indicated a close proximity to the Earth. This minor planet, later designated (433) Eros, was unusual because it was the first such object whose perihelion lay *inside* the orbit of Mars. For that reason, Eros subsequently was used to determine the value of the solar parallax (and the true dimension of the Astronomical Unit).

Witt's discovery of Eros provided an important spur to his astronomical studies and caused him to abandon his stenographic career. In 1905, Witt completed (and published) his doctoral dissertation on the orbital mechanics of Eros, which displayed the strengths of classic astrometry. The following year, he was awarded a Ph.D. by the University of Berlin. In 1908, he deduced a value of 8.803″ for the solar parallax. He was made a *Privatdozent* (a lecturer, paid by student fees) from 1909 to 1920 at the University of Berlin and was appointed director of the Urania Observatory. In 1913, that structure was relocated to Babelsberg, and Witt remained its director until resigning from that post in 1923. In 1902, Witt had married Martha Thiele; the couple had one son and two daughters.

Following his retirement, Witt took an increasing interest in the Berliner Mathematischen Gesellschaft. (Berlin Mathematical Society), and was eventually elected its president. He prepared ephemerides of Eros for its particularly close opposition of 1930/1931. These tables enabled more precise observations to be made, and a more accurate value of the solar parallax to be determined. Witt left unpublished a detailed study of the perturbations on Eros by the gravitational attraction of Jupiter.

In February 2001, the NEAR (Near-Earth Asteroid Rendezvous) Shoemaker spacecraft made a soft-landing on Witt's minor planet (433) Eros – the first such encounter ever attempted. This highly elongated, 33 × 13 km object is heavily cratered and has a rotation period of only 5.3 hours. Had Witt been alive on this occasion, he doubtlessly would have been thrilled to learn the true nature of this unusual asteroid discovered by him, more than 100 years earlier in Berlin.

Jordan D. Marché, II

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Wittich, Paul

Born **Breslau (Wroćlaw, Poland), *circa* 1546**
Died **Vienna, (Austria), 9 January 1586**

Paul Wittich was one of many late-16th-century mathematicians who pursued the project of geometrically modifying the Copernican models of planetary motion to adapt them to a central Earth. He also studied the trigonometric problem of prosthaphaeresis.

Little is known about the family of Paul Wittich except that his uncle was the physician of Wroclaw Balthasar Sartorius, and that he was survived by a sister who inherited his books and his papers. The first known record of Wittich concerns his matriculation at the University of Leipzig in the summer of 1563. He later matriculated at Wittenberg, in June 1566, and at Frankfurt an der Oder, in 1576, but he is not known to have received degrees from these or any other institutions. Wittich seems to have preferred the lifestyle of the itinerant scholar: He wandered widely in between attending these universities, and indeed subsequently.

Wittich was a talented mathematician, and his contributions to astronomy derive from the combination of his mathematical interests and his peripatetic lifestyle. He wanted to transform the Copernican models of planetary motion so as to adapt them to the stability and centrality of the Earth. He also worked on prosthaphaeresis, a method of reducing problems involving the multiplication and division of trigonometric functions to ones of addition and subtraction. Wittich's progress in both of these fields is attested by annotations he made to the several copies of *De Revolutionibus* that he owned, and marginalia in further copies of **Nicolaus Copernicus**' text are among the sources that indicate the transmission of these ideas to others.

During the course of his travels, and the intermittent sojourns in his hometown of Wroćlaw, Wittich met many individuals actively interested in mathematics and astronomy with whom he collaborated or whom he instructed. His known contacts include the Altdorf professor Johannes Praetorius, the imperial physician **Tadeá Hájek z Hájku**, the Oxford mathematician **Henry Savile**, and the Scottish physicians **John Craig** and **Duncan Liddel**. (It is possible that Wittich's "discovery" of the first prosthaphaeretic identity was facilitated by Johannes Praetorius, who had come into contact with a manuscript by **Johannes Werner** that contained it.) In the late 1570s, Wittich communicated the prosthaphaeretic method to Craig, who later shared it with **John Napier**; he also divulged his work on planetary models to Savile in 1581. The most consequential of Wittich's collaborations, however, resulted from his visits to the two chief centers of astronomical endeavor in the late-16th century, the observatories of **Tycho Brahe** and Landgrave **Wilhelm IV** of Hesse.

In the autumn of 1580, Wittich visited Brahe's observatory in Denmark, revealing to him the first prosthaphaeretic identity and showing him his geometrical manipulations of the Copernican planetary models. Both were important to Brahe's astronomical project: Prosthaphaereois greatly simplified the task of reducing observational data, and by a slight alteration of Wittich's models, Brahe would arrive at the geoheliocentric scheme he promoted as the true system of the world. Brahe envisaged a long and fruitful collaboration with Wittich, but for reasons that are unclear, Wittich left Uraniborg after only a few months, deceiving the Danish astronomer with a promise to return.

In 1584, Wittich made his way to Kassel, where he worked with Wilhelm's mechanic **Jost Bürgi** in improving the instruments of the observatory of Kassel according to the design principles employed at Uraniborg. When Brahe learned of this collaboration, he was angered by the fact that Wittich had not credited him with these improved instrument designs; however, Brahe quickly came to appreciate the close agreement between the observational data produced at Uraniborg and Kassel that resulted. Wittich also designed an astrolabe for Landgrave Wilhelm, and he divulged to Bürgi the first prosthaphaeretic identity. Bürgi went on to discover a second, with proofs for both, and later showed these to **Nicholaus Bär** (Raimarus Ursus). As a consequence, Brahe's priority dispute with Bär over the invention of the geoheliocentric world-system was entangled with the quest to establish priority for himself and Wittich in the development of prosthaphaeresis.

Wittich also made observations, some of which he shared with other astronomers. However, both **Christoph Rothmann** and Brahe declared that Wittich was a poor observer, and in this respect was a better mathematician than astronomer.

Adam Mosley

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Wolf, Charles-Joseph-Étienne

Born **Vorges, Aisne, France, 9 November 1827**
Died **Saint-Servan, Ille-et-Vilaine, France, 4 July 1918**

Charles Wolf and **Georges Rayet** have their names associated with a category of peculiar stars that they discovered at the Paris Observatory. Wolf came from an Alsatian family, the son of Pierre Frédéric Wolf, then lieutenant du Régiment des Chasseurs britanniques, and of Marie Josèphe (*dite* Louise) Pirachet. Several of Wolf's brothers likewise acquired positions in the field of teaching. Having passed the entrance exam, Wolf was admitted to the École Normale Supérieure in 1848 and studied physics; he graduated (*agrégé de physique*) in 1851. Wolf first taught at the Lycée of Nîmes and later at Metz, where he was married. His wife died prematurely, leaving him to raise their only child, a daughter.

Wolf's first research investigated capillarity as a function of temperature; for this work, he was awarded the degree of *Docteur d'État ès sciences de la Faculté de Paris* in 1856. He then transferred to the faculty of sciences at the University of Montpellier. There, he conducted experiments on the spectra of the alkali metals and found that these too displayed a variation with temperature. These findings were noticed by **Urbain Le Verrier**, director of the Paris Observatory, who offered Wolf a position as assistant astronomer in 1862.

First assigned to the Service Méridien, Wolf completed a study of the so called personal equation affecting meridian observations of stars. He also devised a direct-view spectroscope that was employed at the Service des Équatoriaux. A few years later, he was placed in charge of these instruments.

With his spectroscope, Wolf first observed some bright emission lines in the spectrum of a nova (T Coronae Borealis) on 20 May 1866. He then undertook a systematic search for similar lines in the spectra of other stars. In 1867, using **Jean-Bernard-Léon Foucault**'s 40-cm silvered-glass reflector, he and Rayet discovered three eighth-magnitude stars that are now known as Wolf–Rayet stars. Today, more than 100 such objects are known. Wolf–Rayet stars exhibit broad emission lines of helium, carbon, and nitrogen in their spectra. The outer layers of these highly evolved stars have been stripped away, revealing their exceptionally hot cores. Such stars are often found at the centers of planetary nebulae.

In 1869, Wolf explained the problem of the "black drop" effect, seen during transits of Mercury or Venus across the Sun's disk, as a purely instrumental consideration that arose from the contrast gradients of the two images. Wolf personally observed the 1874 and 1882 transits of Venus as tests of his ideas. Between 1873 and 1875, he prepared the most complete astrometric catalog of the Pleiades star cluster (achieved by visual means), giving the positions and magnitudes of more than 500 of its members. His results were superseded only by the development of astronomical photography. Wolf was made an assistant at the Sorbonne (1875), where he taught physical astronomy, and was a delegate to the Astrographic Congress (1887). He left the observatory in 1892 to devote full time to teaching.

Wolf undertook a historic study of the standard weights and measures housed in the collections of the Paris Observatory. In 1902, he published a definitive history of the Paris Observatory from its founding to the year 1793, drawn upon studies of original documents preserved in its archives and elsewhere.

Wolf retired in 1901 and returned to his native town but was forced to leave it when France was occupied during World War I. He was elected to the Paris Académie des sciences (1883) and later served as its president (1898).

Solange Grillot

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Wolf, Johann Rudolf

Born **Fällanden, (Zürich), Switzerland, 7 July 1816**
Died **Zürich, Switzerland, 6 December 1893**

Johann Wolf is best known for his observations of sunspots and, in particular, his development of a formula for describing the number of observed sunspots. Wolf was born to Johannes Wolf (1768–1827), the fourth generation of Evangelical pastors in his family, and to Regula Gossweiler (1780–1867), a daughter of a Protestant minister. Wolf claimed to owe his scientific career in large part to his older brother, Johannes, who first announced his intention to carry on the family's religious tradition.

Wolf began his education at the Technological Institute in Zürich, but soon transferred to the newly founded Zürich University in 1833, where he studied until 1836, though he left without receiving a degree. He spent the following 2 years traveling to various universities and observatories across Europe. His most important steps on this journey were:

(1) an extended 18-month stay in Vienna, where he attended physics and astronomy lectures at the university and worked with **Johann von Littrow**;
(2) a 4-month stay in Berlin, where he rubbed shoulders with a number of established physicists and astronomers at the Berlin Observatory and the Academy of Sciences;
(3) a short but influential stay at the Göttingen Observatory, where he was introduced by **Karl Gauss** to contemporary geomagnetic theories and measurements; and,
(4) his visit to Gotha, where he became acquainted with the library collection and historical researches of **János von Zach**.

Wolf returned to Zürich at the end of 1838, and the following year began teaching mathematics, physics, and astronomy in Bern, where he became director of the local observatory in 1847. In 1855, he moved back to Zürich with a triple appointment as lecturer in mathematics at the Hochschule, extraordinary professor at the university, and professor of astronomy at what is now the Eidgenossische Technische Hochschule [ETH]. Wolf subsequently became the first director of the Federal Observatory inaugurated at the ETH in 1864, a position he held until his death. He was a member of the Swiss Naturforschenden Gesellschaft already in his student days, and over the years presided over its Bern and Zürich chapters. Wolf was also for a time director of the Swiss Meteorological Headquarters, and president of the Commission on Meteorology and Geodesy. He was elected a foreign member or associate of the Astronomische Gesellschaft Leipzig (Germany, 1850), the Società degli Spettroscopisti (Italy, 1859), the Royal Astronomical Society (England, 1864), and the Académie des sciences (Paris, 1885). He was granted an honorary doctorate by Bern University in 1852. Wolf never married, and after enjoying good health throughout his life, died after a short illness.

Wolf's astronomical interests ranged from comets to nebulae, but by far his most important contribution to astronomy was his historical reconstruction of solar activity based on sunspot numbers. His interest in such matters was fired by the observation of a particularly large and long-lived sunspot group in December 1847. Already aware of **Heinrich Schwabe**'s 1843 announcement of the sunspot cycle, Wolf embarked on his own sunspot-observing program. Using observatory records from across Europe, he began a program of historical researches aimed at extending sunspot cycle data prior to Schwabe's observations. In 1850, he introduced his relative sunspot number (R_Z), defined as

$$R_Z = k\,(10g + f),$$

where g is the number of sunspot groups observed on a given day, f the number of individual sunspots, and k a numerical scaling coefficient. Setting $k = 1$ for his own observations, Wolf assigned distinct k values to different observers, so that their numerical values for g and f would yield the same R_Z on common observing days. This simple rescaling procedure thus allowed him to put on the same numerical scale sunspot observations carried out by observers of widely varying ability and diligence, and using equally widely varying instruments and techniques.

By 1852, Wolf had revised Schwabe's 10-year cycle duration to an average value of $11^{1}/_{9}$ years, and offered evidence for significant variations in the cycle's duration, an anticorrelation between cycle amplitude and duration, and longer, secondary periodicities superimposed on the primary cycle. By 1868, he had extended his sunspot number reconstruction back to 1700. Wolf continued to revise his time series of sunspot numbers throughout his life, as more and more data became available to him. His successors in Zürich continued his work for nearly a century, with the Brussels Observatory carrying on the tradition since 1981. The Wolf sunspot number, as it is now called, remains to this day the classical (and most intensely studied) measure of solar activity.

In July 1852, Wolf was one of four researchers (along with **Edward Sabine** in England, **Johann von Lamont** in Germany, and **Jean Gautier** in Switzerland) to demonstrate independently and more or less simultaneously that a marked 11-year periodicity also appears in geomagnetic measurements. Wolf went on to discover the correlation between sunspot numbers and auroral records, also independently noted by American scientist **Elias Loomis**. Wolf continued to seek sunspot-related periodicities in various meteorological phenomena, but with inconclusive results.

Throughout his life, Wolf was very active in the Bern and Zürich chapters of the Swiss Naturforschenden Gesellschaft, and contributed numerous papers to the society's *Vierteljahrsschrift*, for which he also acted as editor for many years. Already in 1855, Wolf's wide-ranging interests and scholarship led to his appointment as the first ETH librarian, and it was largely through his initiative that the library's remarkable historical collections were assembled. Other technical interests of his included geodesy, surveying, number theory, and the empirical study of probability.

Wolf was an indefatigable worker and a prolific writer by any standards. In the course of his career, he authored some 258 articles or books in the fields of astronomy, meteorology, mathematics, surveying, and the history of science, culture, and religion. He also regularly penned articles and delivered lectures aimed at the general public. In 1856, Wolf inaugurated his solo astronomical journal, *Astronomische Mittheilungen*, adding up to 13 volumes by the year of his death, and in which he published results of his astronomical and historical researches.

Paul Charbonneau

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Wolf, Maximilian Franz Joseph Cornelius

Born **Heidelberg, (Germany), 21 June 1863**
Died **Heidelberg, Germany, 3 October 1932**

Max Wolf, considered a pioneer in astrophotography, observed many new nebulae both within the Milky Way and outside our Galaxy. He discovered more than 200 asteroids along with three comets that now bear his name.

Wolf was born to Franz Wolf and Elise Helwerth. As Wolf became interested in astronomy, his father, a physician, constructed a private observatory for him, which he used from 1885 until 1896. In 1884, when only 21 years old, he discovered comet 14P/Wolf. This discovery was remarkable because the object was first thought to be an asteroid.

Wolf received his Ph.D. from Heidelberg in 1888 working under Leo Königsberger. He then studied with **Hugo Gyldén** in Stockholm from 1888 to 1890. Wolf became *Privatdozent* (lecturer) in 1890 and served as professor of astrophysics and astronomy at the University of Heidelberg from 1893 to 1932. He prompted the building of a new observatory near Heidelberg at Königstuhl, and became its director. Wolf is now also known as the "Father of Heidelberg astronomy."

Wolf developed several new photographical methods for observational astronomy, and was the first astronomer to use time-lapse photography, useful, for example, in detecting asteroids. Wolf brought the "dry plate" technique to astronomy in 1880, and introduced the blink comparator in 1900 in conjunction with the Carl Zeiss optics company in Jena. Using a blink comparator, a microscope that optically superimposes two photographic plates onto the same viewing region by blinking between them so quickly that the two plates look like only one, an astronomer can compare two plates and easily find differences between them. The blink comparator turned out to be a valuable, useful astronomical tool, used in the discovery of Pluto by **Clyde Tombaugh** in 1930. While Wolf himself did not contribute to this discovery, he was able to locate the new planet on his older plates.

Wolf discovered more than 200 asteroids using various photographic techniques. The first, discovered in 1891 during a search for the minor planets (10) Hygiea and (30) Urania, was (323) Brucia, named by Wolf in honor of Catherine Wolfe Bruce, who had contributed $10,000 for one of his telescopes. Already by 1892, while overcoming difficulties with the optics, Wolf had found 17 new asteroids. In 1906, Wolf discovered (588) Achilles, the first of the so called Trojan minor planets, which orbit the Sun in low-eccentricity stable orbits with semi-major axes very close to that of Jupiter. These objects manifest the triangular three-body system analyzed and predicted theoretically by **Joseph Lagrange** in the 18th century.

Wolf was the first to observe comet 1P/Halley when it approached Earth in 1909. Halley's comet produced much excitement the following year because it was so close to the Earth that some expected the Earth would pass through its tail.

Wolf used wide-field photography to study the Milky Way. He discovered about 5,000 nebulae and galaxies and also found new stars, such as Wolf 359, an extremely faint star, the third closest to the Earth after Alpha Centauri 3 and Barnard's star. Though Wolf 359 is much too dim to be visible to the naked eye, Wolf was able to discover it with photographic techniques.

Wolf used statistical star counts to prove the existence of dark nebulae. Independently of American astronomer **Edward Barnard**, Wolf discovered that the dark "voids" in the Milky Way are in fact nebulae obscured by vast quantities of dust. In studying their spectral characteristics and distribution, he was among the first astronomers to show that spiral nebulae have absorption spectra typical of stars and thus differ from gaseous nebulae like planetary nebulae.

Around 1905, Wolf suggested building an observatory in the Southern Hemisphere, though it was not until 1930 that such plans were realized by Berlin and Breslau astronomers in Windhoek (Namibia). Observations there were stopped by World War II. In the 1950s, the European Southern Observatory [ESO] tested two sites in South Africa and South America, with a new observatory opening eventually in 1969 in northern Chile.

Wolf was a co-developer of the stereo comparator together with Carl Pulfrich from the Zeiss company. The stereo comparator consists of a pair of microscopes arranged so that one can see simultaneously two photographic plates of the same region taken at different times. Wolf seems to have experimented with such techniques as early as 1892, but without success. When Pulfrich approached him to adapt the technique from geodesy to astronomy, Wolf was delighted. A steady exchange of letters followed. Wolf and Pulfrich then worked together to analyze the rapidly growing accumulation of photographic plates. Tragically, Pulfrich lost one eye in 1906, preventing him from using the stereographic tool from then on.

Wolf also provided in 1912 suggestions for the idea of the modern planetarium, while advising on the new Deutsches Museum in Munich, Germany. Wolf was a gifted teacher who attracted students from all over the world. He was also highly esteemed by amateur astronomers, helping them out with pictures and slides. In 1930, Wolf became a Bruce Medalist, awarded each year by the directors of six observatories – three in the United States and three abroad. He received the Gold Medal of the Royal Astronomical Society in 1914.

Wolf was survived by his wife Gisela Wolf (*née* Merx), whom he married in 1897. She had assisted him often with his work at the blink comparator. In addition to the three comets, Wolf has a lunar crater, a star (Wolf 359), the minor planet (827) Wolfiana, and an irregular galaxy (Wolf–Lundmark–Melotte) named in his honor.

Oliver Knill

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Wollaston, William Hyde

Born **East Dereham, Norfolk, England, 6 August 1766**
Died **London, England, 22 December 1828**

William Wollaston, an English scientist, physician, and inventor, was a gifted polymath who made important contributions to physiology, optics, mineralogy, and chemistry. Son of Francis and Althea (*née* Hyde) Wollaston, he was first educated at Charterhouse and then admitted to Caius College, Cambridge, where he studied botany. Upon his graduation in 1787, Wollaston pursued a medical degree and received his M.D. in 1793. He was subsequently elected to the Royal Society (London) and later served as its secretary (1804–1816).

In 1800, Wollaston abandoned his medical practice and began instead to pursue scientific research full time. He investigated a vast range of subjects, stretching from human physiology, chemistry, and metallurgy, to theoretical and experimental physics and astronomy. Wollaston identified bladder stones (composed of the first known amino acid) and their method of formation, advocated the use of meniscus lenses in eyeglasses, and made precise analyses of the human hearing mechanism. He discovered how to work platinum, tungsten, and other transition metals, and his original process (employing powder metallurgy) for rendering platinum malleable made him extremely wealthy. Wollaston used the money to further his research. He discovered two new metals, palladium and rhodium. The mineral wollastonite ($CaSiO_3$), widely used in ceramic products such as tiles and porcelain, is named after him. His improvements to the chemical battery were adopted for the rest of the century. Wollaston was one of the avatars of modern atomic theory; his anticipation of the three-dimensional geometrical arrangement of atoms paved the way for the work of John Dalton, Jacobus van’t Hoff, and Joseph le Bel.

In 1802, Wollaston first reported that the solar spectrum was crossed by a series of dark lines; he erroneously took this to mean that there were only four primary colors in its spectrum. These dark lines were investigated a decade later by **Joseph von Fraunhofer**, after whom they are named, although they remained unexplained until chemists **Robert Bunsen** and **Gustav Kirchhoff** laid the foundations of observational astrophysics in 1859.

Much of Wollaston’s research was prompted by his own development of new optical techniques and instruments. He invented the reflecting goniometer, a device used for measuring the angles between facets of crystalline minerals. This instrument had a notable impact on the sciences of crystallography and mineralogy. Wollaston also perfected a new type of sextant, the dip sector, which was used in early exploration near the Earth’s North Pole. In 1807, he designed and built the *camera lucida*, containing a quadrilateral prism that aided the production of making sketches. His improvement of the *camera obscura* (using meniscus lenses) helped to inspire the “fixing” of landscape imagery onto a screen and the invention of photography. Shortly before his death, Wollaston left substantial sums to both the Royal and Geological Societies of London for the encouragement of scientific research.

Daniel Kolak

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Woltjer, Jan, Jr.

Born **Amsterdam, The Netherlands, 3 August 1891**
Died **Leiden, The Netherlands, 28 January 1946**

Dutch theoretical astronomer Jan Woltjer is recognized for a study of the motion of the Saturian satellite Hyperion that provided the first, and still best established, example of what is now called chaotic behavior in an astronomical system. He was the son of Jan Woltjer, Sr., a professor of classical languages at Amsterdam, and received his Ph.D. in 1918 for work on the theory of Hyperion at Leiden University under **Willem de Sitter**. He was a lector at Leiden University (a position which did not permit having formal Ph.D. students) for most of his career. He married Hillegonda Hester de Vries, and they had four children, all scholars: Anna (sociology), Margo (classical languages), Jan Juliaan (history), and Lodewijk (astronomy).

Following his Ph.D., Woltjer continued and completed his study of the complex motion of Hyperion, the seventh satellite of Saturn. Hyperion's orbit presented particular problems because of the strong influence of the very massive satellite Titan. Contrary to **Simon Newcomb**'s earlier skepticism, Woltjer showed that an expansion into powers of the eccentricity of Titan's orbit led to a successful ephemerid for Hyperion. More recently his theory has been taken up again and further elaborated by D. B. Taylor and others.

By the mid 1920s Woltjer's interests had shifted toward astrophysical problems. Among his contributions may be mentioned studies of opacities in stellar interiors, radiative transfer in moving media, and the dynamics of the solar chromosphere. However, Woltjer's most significant work pertained to the pulsation theory of Cepheid variable stars, where he was the first to obtain quantitative results on the excitation of overtone pulsations and their interaction with the fundamental mode. Woltjer succeeded in casting the equations of pulsation theory into a Hamiltonian form, so that the methods of celestial interaction between the fundamental mode and an overtone could limit the amplitude of the pulsations. This also permitted an understanding of the variables with multiple periods like RR Lyrae and ζ Geminorum.

The oscillation of a star would damp very quickly if there were no energy fed into it to compensate the damping. Woltjer developed an iterative procedure to deal with these "nonadiabatic" effects. To first order, the method consists of using the adiabatic equations to compute the flux variations and then utilizing these in the equations for the nonadiabatic temperature variations. From these, the energy input into the oscillation can be obtained. In principle this procedure can be repeated to obtain higher order corrections, but the first step is already quite complex. This method was later used by J. P. Cox and others to quantitatively demonstrate that the helium ionization zone could play an important role in maintaining the Cepheid pulsations. With the advent of powerful computers, direct integration of the hydrodynamic and radiative transfer equations became possible, and the Woltjer method has fallen into disuse.

Woltjer's work was characterized by a search for mathematical rigor, though it was also motivated by observational problems. Unfortunately, World War II, and his untimely death soon after, stopped his work in midstream.

Lodewijk Woltjer

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Wood, Frank Bradshaw

Born **Jackson, Tennessee, USA, 21 December 1915**
Died **Gainesville, Florida, USA, 10 December 1997**

Frank Wood was a leading authority on photometry and eclipsing binary stars and provided leadership to the binary star subcommunity through the International Astronomical Union for a number of years. The son of Thomas Frank and Mary Bradshaw, he received his undergraduate education in Florida. He then earned a Ph.D. in astronomy from Princeton University as a student of **Raymond Dugan**, and then **Henry Norris Russell** when Dugan died, for a dissertation on eclipsing binary stars. Wood remained a specialist in close binary stars for the remainder of his career. He was the first to document that most close binary systems in which irregular period changes are observed are dynamically unstable with at least one member of the pair filling its Roche limit and likely losing mass. However, his physical explanation of the mass loss as occurring in jets directed along the axis of rotation was rejected by most theorists.

As department chair and director of the Flower Observatory and then Cook Observatory, Wood was responsible for the consolidation of these two facilities into one larger Flower and Cook Observatory in Paoli, Pennsylvania, more distant from Philadelphia city lights than either previous observatory. He married Elizabeth Hoar Pepper; they had four children.

Thomas R. Williams

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Wood, Robert Williams

Born **Concord, Massachusetts, USA, 2 May 1868**
Died **Amityville, New York, USA, 11 August 1955**

Robert Wood, a brilliant experimentalist, contributed substantially to our physical understanding of the optical characteristics of gases, including those in magnetic fields; his work was critical to the evolution of astrophysical understanding through the application of the spectroscope to celestial objects. From his laboratory at Johns Hopkins University, Baltimore, Maryland, he supplied many high-precision ruled diffraction gratings that made their way into astronomical spectrographs. Wood's work in color photography led to the design of ultraviolet and infrared filters of importance to astronomy as well.

Wood, son of Robert and Lucy (*née* Davis) Wood, received his B.A. in chemistry from Harvard College in 1891. He then studied at Johns Hopkins University (1892), the University of Chicago (1892–1894), and the University of Berlin (1894–1896), where he became an assistant to physical chemist Wilhelm Ostwald and physicist Heinrich Rubens. Although Wood never earned a doctorate, he taught at the University of Wisconsin (1897–1901) before becoming professor of experimental physics (1901–1938) at the Johns Hopkins University, succeeding **Henry Rowland**. Wood was subsequently named professor emeritus and research professor (1938–1955). He married Gertrude Ames in 1892; the couple had four children.

A prolific inventor, Wood developed methods for thawing frozen water pipes by passing electric currents through them, frosting the insides of glass light bulbs, and introducing the so called Vienna method for detecting forged documents (using ultraviolet light). He was perhaps the first person to show animated films, and successfully demonstrated the principles of fisheye camera lenses and photography. Wood conducted pioneering investigations in the fields of ultrasound and biophysics, including the first study of the physiological effects of high-frequency sound waves.

Wood made a number of fundamental contributions to optics and spectroscopy. He greatly improved the efficiency of diffraction gratings with his design of the echelette grating, which allowed selection of a narrow range of wavelengths for detailed study. In 1897, he became the first person to observe the "field emission" of charged particles from a collector placed in an electric field. Wood's studies on the fluorescent properties of gases had profound implications for the theory of atomic structure. He was nominated in 1927 for the Nobel Prize in Physics by **Erwin Schrödinger**, but did not receive the award. Wood, however, received several honorary doctorates in his career.

Although the discovery of radiation beyond the visible spectrum and techniques of sensitizing photographic emulsions to record them predated Wood's activities, he was the first to make photographic filters that excluded visible wavelengths. He was also the first to capture ultraviolet fluorescence on film. Although infrared emulsions would not be commercially available until the 1930s, Wood published infrared landscape photographs taken with experimental films *circa* 1910. That same year, Wood undertook the first spectrophotometric investigation of the Moon, identifying localized chromatic differences in lunar soils. A region near the crater Aristarchus that appears dark in ultraviolet radiation is often referred to as Wood's spot. The Wood lamp for generating ultraviolet radiation, but commonly referred to as a "black light," bears his name.

In the early 1900s, Wood conducted experiments with rotating mercury mirrors. By applying various rotation speeds to pools of the liquid metal, Wood demonstrated the feasibility of turning them into paraboloidal mirrors for reflecting telescopes. He even hoped to find some substance that could be allowed to solidify while rotating, thereby saving most of the labor expended in constructing such telescope mirrors. Although not realized in Wood's day, this principle was later applied by the University of Arizona astronomer Roger Angel, whose rotating kilns enabled the production of giant (8 m) "spun-cast" glass telescope mirrors.

A highly visual thinker, Wood wrote in his textbook, *Physical Optics*, that he had "attempted to give, in as many instances as possible, a physical picture of the processes usually described by equations." Throughout his life, Wood retained a mischievous nature; his principal biographer, William Seabrook, styled Wood as a "small boy who … never grew up."

In 1912 Wood was elected to the US National Academy of Sciences, from which he received the Henry Draper Gold Medal for his contributions to astronomy. He was one of few foreigners elected as a member of the Royal Society of London, and received that society's Rumford Gold Medal for his achievements in physical optics. Wood served as president of the American Physical Society (1935). He authored *Physical Optics* (1905), a standard textbook on the subject for many years, along with *Researches in Physical Optics* (1913–1919), and *Supersonics, the Science of Inaudible Sounds* (1939), along with more than 220 scientific articles. Wood is also known for *How To Tell the Birds from the Flowers* (1907), a book of nonsense verses written to amuse his children, and *The Man Who Rocked the Earth* (1915), a science fiction novel coauthored with Arthur Train. He is commemorated by a 78-km diameter crater on the Moon. A collection of Wood's papers is held at the Niels Bohr Library of the American Institute of Physics.

Thomas A. Dobbins

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Woolley, Richard van der Riet

Born **Weymouth, England, 24 April 1906**
Died **Sutherland, South Africa, 24 December 1986**

British optical astronomer Richard Woolley is most happily remembered for his role in the postwar development of optical astronomy in Australia, Britain, and South Africa, and less happily for having firmly said that spaceflight would always be impossible, shortly before it became a reality. Woolley was the son of a rear admiral who had been stationed at Simonstown, near Cape Town, South Africa, and a South African mother (whence the name van der Riet), daughter of the resident magistrate there. Woolley began his education in England, but returned to South Africa when his father retired there, earning a B.Sc. in 1924 and an M.Sc. in 1925 at the University of Cape Town, and briefly holding a position as demonstrator in physics there.

Woolley returned to England, to Cambridge University in 1926, receiving a high-rank degree in mathematics in 1928. Encouraged to take an interest in astronomy by professor **Frederick Stratton**, Woolley began work on solar and stellar atmospheres with **Arthur Eddington** and received a Ph.D. in 1931, partly for work on the solar spectrum carried out at the Mount Wilson Observatory, California, USA, under a Commonwealth Fellowship.

After 2 years on an Isaac Newton Studentship at Cambridge, Woolley was appointed chief assistant at the Royal Greenwich Observatory, where he wrote the book *Eclipses of the Sun and Moon* with **Frank Dyson**, then the Astronomer Royal. After 2 more years in Cambridge (1937–1939) as assistant to Eddington, Woolley was appointed Commonwealth astronomer and director of the Commonwealth Solar Observatory in Canberra, Australia. Almost immediately, he put it on a war footing, devoting its optical expertise to the design of gun sights and the like.

After the war, Woolley arranged for the transfer of the observatory, renamed the Mount Stromlo Observatory, from the government to the newly founded Australian National University. His own work, meanwhile, had shown that the upper chromosphere of the Sun was hot, in collaboration with **Clabon Allen** (best known as the editor of several iterations of *Allen's Astrophysical Quantities*), though the mechanism they suggested (back-warming from the corona) cannot be the whole story. A collaboration with Douglas W. N. Stibbs resulted in an important book on stellar atmospheres in 1953. Woolley had arranged for the financing and construction of a 1.9-m telescope for Mount Stromlo, which was installed not long after he had returned to England in 1956 as Astronomer Royal and director of the Royal Greenwich Observatory [RGO].

Once again Woolley engaged in a great deal of hard work in the realm of scientific politics, connected with the transfer for RGO from its hopeless site near London to the only slightly less hopeless site near Brighton, Sussex (at Herstmonceux), and the construction and commission of the Isaac Newton telescope (a 98-in., eventually relocated, at least in parts, to La Palma in the Canary Islands, where it finally became a productive instrument). Woolley initiated the annual Herstmonceux Conferences in astronomy and the student summer courses as well as inaugurating new programs in photometry and dynamics of nearby stars. He collaborated with new staff member Olin J. Eggen and with **Olin Wilson** on determinations of stellar distances, ages, and velocities.

Woolley's next major initiative was the Anglo–Australian Telescope, a 4-m class instrument, to be sited under clear, southern skies but jointly owned and operated. His age-dictated retirement as Astronomer Royal in 1971 occurred before this project was completed.

Returning to South Africa, Woolley engaged yet again in observatory building. Three separate existing facilities, all short of funds and modern instrumentation, were merged to form the South African Astronomical Observatory at Sutherland under his directorship. There he encouraged work on abundances of the elements in stars and galaxies and on quasars. His own work continued after yet another retirement in 1976. It included exploitation of infrared light curves to improve the Baade–Wesselink method for determining brightnesses and distances to Cepheids (and other variable stars) and determination of the kinematics of the older RR Lyrae stars in the galactic halo.

Woolley served as a vice president of the International Astronomical Union (1952–1958) and president of the Royal Astronomical Society (1963–1965). He was elected to the Royal Society (London) in 1953, received a Sc.D. from Cambridge in 1951, and was knighted in 1963. His first two wives predeceased him, and he was survived by the third, Sheila Woolley.

Roy H. Garstang

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Wren, Christopher

Born **East Knoyle, Wiltshire, England, 20 October 1632**
Died **London, England, 25 February 1723**

Sir Christopher Wren, remembered mostly for his architecture, was a key figure in the nascent Royal Society of London. Wren was the son of Reverend Christopher and Mary Wren, a royalist family. In 1634 the elder Christopher was appointed dean of Windsor and registrar of the Order of the Garter. Christopher was tutored by his father, who had some knowledge of mathematics, modern science, and architecture, and then by Reverend William Holder, later a fellow of the Royal Society. He entered Westminster School in 1642; John Dryden and John Locke were fellow students. Westminster was one of the few schools to offer mathematics. In 1647 Wren went to live in the London home of physician Charles Scarborough, first as a patient and then as a sort of student assistant. Here he met a number of prominent scientists, some of them refugees from the Puritan stronghold of Cambridge. Wren translated a tract on sundials by William Oughtred into Latin. It was appended to the 1652 edition of *Clavis Mathematica*, and Oughtred praised him as a youth

who had already enriched astronomy and other sciences, prefiguring John Evelyn's famous words,"that miracle of a youth, Christopher Wren."

In 1649 Wren matriculated at Wadham College, Oxford, whose master, **John Wilkins**, became his mentor. Wren's talent and temperament led to his acceptance by his scientific seniors. Wren had an interest in instrumentation, a mechanical flair, and a bent for invention, which he used in his own research, and also in setting up apparatus for others. His steady hand in dissection and artistic talent were also shared. Wren was a member, along with Robert Boyle, **Seth Ward**, and **Robert Hooke** of the "Experimental Philosophical Club" formed by William Petty. Hooke praised Wren's pioneering work in microscopic illustration in *Micrographia*.

Wren's interests turned to astronomy and mathematics. Ward had established an observatory at Wadham with telescopes of 6-, 12-, and 22-ft. focal lengths, where they made joint observations. Wren also joined the amateur Sir Paul Neile in observations through the 35-ft. telescope on his estate. Wren and **John Wallis** collaborated on an 80-ft. telescope that could supposedly view the full face of the Moon. Wren earned his AB in 1651 and his MA in 1653; he was awarded a fellowship in All Souls College.

Wren was named professor of astronomy at Gresham College, London, in 1657, possibly through Oliver Cromwell's intervention. On Charles II's restoration in 1660, Wilkins and Ward lost their posts, but Wren, of a royalist family, was appointed to the Savilian Professorship of Astronomy in 1661. Both Oxford and Cambridge awarded him the Doctor of Civil Laws degree in the same year. Wren was frequently in Oxford during his Gresham years, and in London after assuming the Savilian chair, allowing him to attend meetings of what became the Royal Society; he was a charter fellow (July 1662) and president (1681–1683).

Wren undertook his first architectural assignments in the early 1660s, and was appointed by King Charles to the commission to restore the dilapidated Saint Paul's Cathedral. He continued to make astronomical observations with Hooke. During his 1665 trip to study advanced French architecture, his most frequent companions were the astronomers **Adrien Auzout** (whose observations of the 1664 comet (C/1664 W1) agreed with Wren's), Henri Justel, and **Pierre Petit**, savants who shared his interest in both science and architecture.

The Great Fire of 1666 opened the way for Wren's great work. He was appointed Surveyor General (royal architect) in 1669, but not until 1673 did he resign the Savilian professorship. King Charles conferred a knighthood also in 1673.

Wren married Faith Coghill in 1669. Their first son, Gilbert, died in infancy. But Christopher, Jr., lived to be his father's colleague, heir, and literary executor. The first Lady Wren died of smallpox in 1675. Wren remarried, to Jane Fitzwilliam, in 1677. Their daughter Jane was talented in music and art, but their son William was retarded. The second Lady Wren died in 1679, and Wren lived the rest of his long life as a widower.

Wren's architectural achievements are self-evident. He invented the English Baroque style. Saint Paul's Cathedral, London, is his masterpiece. Wren built parish churches, hospitals, academic buildings, and the Royal Observatory in Greenwich. In addition, he found time to serve as president, vice president, and member of Council for the Royal Society, on the Committee of the Hudson Bay Company, and for a couple of terms as a member of parliament.

Wren was singled out in Thomas Spratt's *History of the Royal Society* (1667) where contributions to refraction, theory of motion, the rings of Saturn, his lunar globe, and celestial mapping are mentioned. Wren was a Baconian experimentalist who seemed satisfied with a well-warranted hypothesis. Unlike **Isaac Newton**, he was disinclined to venture into comprehensive theory or writing definitive papers. Some of his scientific papers were extant in 1740 when Ward wrote his *Lives of the Professors of Gresham College*. They are now lost.

Wren's 1657 inaugural lecture at Gresham College, which survives, was considered a definitive statement of the experimental philosophy. A 1659 paper on **Johannes Kepler**'s second law of planetary motion was extremely helpful to English astronomers, most of whom accepted elliptical orbits, but did not understand them. Wren was the leading authority on lunar geography, apparently incorporating a micrometer in the eyepiece of his telescope to refine his measurements. The public product was a 10-in. globe showing the visible face of the Moon in relief, which he presented to King Charles in 1661. Less triumphant was Wren's work on Saturn. He hypothesized that the appearance of the planet was due to an elliptical corona. But the elegance of **Christiaan Huygen**'s ring hypothesis appealed to him. Wren endorsed it and dropped his own work (1659). Indeed his 1658 copper model may illustrate Huygen's view better than his own!

The Great Comet of 1664 provided the occasion for joint observations and intense discussion with Hooke. Wren accepted the popular notion that comets traveled in linear paths, while Hooke speculated about closed, possibly circular, orbits. When a second comet appeared in 1665 (C/1665 F1), probably the same one outbound after passing behind the Sun, Wren remarked it might be the same comet, but apparently took the notion no further.

In 1663 Wren constructed a double telescope with a measuring scale that would enable two observers to focus on the same object and more accurately estimate the distance. Wren built the Royal Observatory in 1675. The building itself has an observation room where smaller telescopes could be used, but the heroic instruments of the day would be suspended from booms in the yard.

In 1692 Wren was involved in a scheme to mount a 123-ft. telescope in a staircase at Saint Paul's, but it did not work. Wren also kept one of the west bell towers clear so that it could be used as an observatory.

At the time of Wren's death he was combining study of Scripture with efforts to solve the problem of determining longitude at sea by some astronomical method.

Christian E. Hauer, Jr.

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Wright, Chauncey

Born **Northampton, Massachusetts, USA, 20 September 1830**
Died **Cambridge, Massachusetts, USA, 12 September 1875**

Inspired by reading Herbert Spencer, American philosopher Chauncey Wright imagined an evolutionary cosmogony of the Solar System in which planets form by "meteoric aggregation" and gradually spiral inward toward the Sun.

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Wright, Thomas

Born **Byers Green near Durham, England, 22 September 1711**
Died **Byers Green near Durham, England, 25 February 1786**

Thomas Wright, the third son of carpenter and yeoman John Wright, was largely self-taught in mathematics, astronomy, and navigation. He made a living in the 1730s by surveying aristocratic estates and teaching public and private courses in the physical sciences. In 1742, Wright declined a position as professor of navigation at the Imperial Academy of Sciences in Saint Petersburg, Russia. Since he never held a formal teaching position, Wright's primary influence came *via* his publications. He never married and was survived by a daughter.

Wright's lifelong preoccupation involved reconciling religious views with astronomical knowledge. Therefore, in order to understand his cosmological speculations, one must not impose modern expectations on Wright's ideas. Through the German philosopher **Immanuel Kant**, Wright became known, though mistakenly, as the originator of the explanation of the Milky Way as a disk-shaped system. In contrast, Wright emphasized the idea that the physical or gravitational center of the Universe must necessarily coincide with the moral or supernatural center. Hence, he insisted on a spherical system. Ironically, Wright's astronomical significance is that he was later credited, by Kant and later writers, as the father of the modern explanation of the Milky Way Galaxy, an idea that he did not develop.

Robinson M. Yost

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Wright, William Hammond

Born **San Francisco, California, USA, 4 November 1871**
Died **San Jose, California, USA, 16 May 1959**

William Wright distinguished himself as a spectroscopist, planetary photographer, and observatory director in a career that spanned an early period of rapid growth in astrophysics. Wright's spectroscopic studies of novae and planetary nebulae measured many lines not previously detected, traced the evolution of gas shells in novae, and demonstrated the increase in energy levels in planetary nebulae as the central or progenitor star is approached. His photographic studies of the planets, especially Mars, applied new multicolor techniques that revealed characteristics not previously observed.

The son of Seldon Stuart and Joanna Maynard (*née* Shaw) Wright, William earned the BS degree in Civil Engineering at the University of California in 1893 and was a graduate student at the Universities of California and Chicago (the Yerkes Observatory) from 1894 to 1897. He was appointed assistant astronomer at the Lick Observatory in 1897.

In 1903, as a last minute replacement for **William Campbell**, Wright selected the site for and supervised the construction of the Lick Observatory's Southern Station near Santiago, Chile. After establishing the observational and data reduction procedures, he remained in Santiago for 3 highly productive years. Wright returned to the Lick Observatory in 1906 and was promoted to astronomer in 1908.

Some of Wright's early work was on novae; he observed the spectrum of Nova Geminorum 1912 (with Campbell), Nova Ophiuchi 1919, and at least eight other novae up to 1933. His observations highlighted the complexity of the phenomena occurring in such stellar explosions, and traced the evolution of the spectrum of the nova into one similar to that of a gaseous nebula as the event matured. Wright's work on the spectra of novae laid the foundations for our modern understanding of this stage in a star's life.

From 1912 to 1919, Wright also made spectroscopic observations of gaseous nebulae, photographing 70 emission lines in the region between 3,313 Å and 6,730 Å and determining accurate wavelengths for most of them. (Thirty of those lines had not been previously observed, and only a few had had well-determined wavelengths.) He showed that the nuclei of planetary nebulae have spectra like those of Wolf–Rayet stars and that the higher excitation emission lines are more intense in the inner portions of planetary nebulae.

Spectroscopic studies of stars in general became possible only toward the end of the 19th century. Neither gaseous nebulae nor novae were fully understood at the time when Wright began his career. **William Huggins** had observed emission-line spectra of what were then called *diffuse nebulae* in 1864, showing that some of these nebulae were gaseous clouds and not unresolved star clusters. Wright's work, by providing accurate wavelengths for the emission lines, helped to elucidate the physical conditions within these nebulae. His data were used by **Ira Bowen** for the crucial identification of these lines with forbidden transitions among energy levels of ionized oxygen, nitrogen, neon, and other elements.

From 1924 to 1927, Wright photographed the planets in six different colors from 3600 Å to 7600 Å. In his work, which extended further into both the ultraviolet and the red ends of the spectrum than had previously been possible, Wright used special emulsions prepared by the Eastman–Kodak chemist and amateur astronomer Charles Edward Kenneth Mees (1882–1960). Wright claimed the photographs showed the Martian atmosphere to be about 60-miles deep and that the polar caps were partly atmospheric phenomena. However, his conclusions in this regard were subjected to a polite but scathing criticism by **Donald Menzel**, who was in a postdoctoral fellowship at Ohio State University, but later worked with Wright at the Lick Observatory. Wright's composite photograph showing one half of Mars photographed in infrared light and the other half in ultraviolet showed clearly the larger apparent diameter of the ultraviolet image and was a favorite illustration in texts and popular books for some time.

Wright's final research, which he did not live to finish, was to work on using the extragalactic nebulae (as they were then called) as fixed reference points for the system of fundamental astronomical constants. His intent was to develop a reference system completely isolated from the inertial system of the Milky Way Galaxy to permit the most unambiguous possible measurement of stellar proper motions. Development of the project took place over a number of years and involved the design of a special 20-in. widefield astrographic telescope by **Frank Ross**. Construction of the telescope by J. W. Fecker was delayed by World War II, but Wright lived to be present during the first and last exposures in the first series of plates. The second series of plates were not exposed until two decades later, but the program began to make positive contributions in the 1960s, particularly in the form of the Shane-Wirtanen counts of galaxies.

Wright made many other contributions to instrumental design. In particular, when the original Mills spectrograph was replaced with the new Mills, Wright introduced several innovations that were quickly copied by the staffs of other observatories engaged in spectroscopic research with spectrographs at the Cassegrain focus. Principally, these innovations were: support of the spectrograph at both ends, to reduce flexure; enclosure of the spectrograph and its support network in an insulated and thermostatically controlled box to eliminate temperature changes during the night; and a means of impressing the comparison spectrum without interrupting the stellar exposure.

From 1935 to 1942, Wright was the director of the Lick Observatory. During his tenure as director, he is credited with strengthening the staff by recruiting younger astronomers, while at the same time opening up the observatory scientifically by inviting astronomers from other observatories and other nations such as **Ejnar Hertzsprung** and **Polydore Swings** for extended visits. These enhancements enriched observatory life and ensured the continued productivity of the Lick Observatory although it would be several decades before an instrument with an aperture larger than 36-in. would be available on Mount Hamilton.

Wright was elected to the US National Academy of Sciences in 1922 and received the academy's Henry Draper Medal in 1928. In that same year, he received the Janssen Medal of the Paris Academy of Sciences. Wright was elected an associate of the Royal Astronomical Society in 1915 and was awarded that society's Gold Medal in 1938. He received honorary degrees from Northwestern University (DSc 1929) and the University of California (LLD 1944). Wright married Elna Warren Leib on 8 October 1901; they had no children.

Wright's correspondence and personal papers are in the Mary Lee Shane Archives of the Lick Observatory, University of California at Santa Cruz.

Alan H. Batten

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Wrottesley, John

Born **near Wolverhampton, Staffordshire, England, 5 August 1798**
Died **Wrottesley Hall, Staffordshire, England, 28 July 1867**

John, Lord Wrottesley (Second Baron of Wrottesley) contributed to 19th-century astronomy as a persistent observer and as an effective administrator of scientific organizations. He was educated at Corpus Christi College, Oxford (BA: 1819; MA: 1823), and married Sophia Elizabeth, third daughter of Thomas Gifford in 1821. His primary career was as a lawyer.

From May 1831 to July 1835, Wrottesley observed the right ascensions of stars from the sixth to seventh magnitudes. For this accomplishment he was awarded the Royal Astronomical Society's Gold Medal in 1839. In 1842, Wrottesley began construction of an observatory near his home containing an achromatic refracting telescope of 10-ft. 9-in focal length. He communicated his observations to the Royal Society; his primary research, based upon an earlier suggestion of **John Herschel**, involved the determination of parallax for optical double stars. He later performed research on the statistical calculation of errors related to stellar observations.

Wrottesley perhaps made his greatest contributions to science as an administrator selected by his colleagues. Ten years of service as secretary of the Royal Astronomical Society [RAS] (1831–1841), which overlapped the presidencies of John Herschel, **George Airy**, and others better known than he, were succeeded by the presidency of the RAS (1841), of the Royal Society (1854–1857, to which he was elected in 1841), and of the British Association for the Advancement of Science.

Robinson M. Yost

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Wurm, Karl

Born **Siegen, (Nordrhein-Westfalen), Germany, 21 July 1899**
Died **Rosenheim, Bavaria, (Germany), 16 February 1975**

German astronomer Karl Wurm contributed to measurements of the properties of diffuse gas around hot stars, particularly the measurement of the density of the shells around Be Stars, and of the temperatures of the stars at the centers of planetary nebulae, and to the analysis of the emission line spectra of comets.

Wurm studied at Bonn University between 1921 and 1927, receiving his Ph.D. for work with R. Mecke on problems of molecular physics. He spent the next 14 years at the astrophysical observatory at Potsdam, with an interval (1938/1939) as visiting professor at the University of Chicago. His work there with **Otto Struve** on helium lines in the spectra of gaseous nebulae was his most cited work.

In 1941 Wurm went to the Bergedorf Observatory near Hamburg as deputy observer, was promoted in 1943 to observer, and began lecturing at the Hamburg University in 1946. In 1950 he went to the Humboldt University in Berlin as visiting professor but returned to Hamburg as head observer after only a year. From 1961 onward he visited at Mount Hamilton as a Morrison Research Associate of the Lick Observatory.

Between 1958 and 1964 Wurm was president of the International Astronomical Union Commission 15, Physical Studies of Comets and Minor Planets. In 1954 he began a collaboration with the Astrophysical Observatory of Asiago, the University of Padova, which lasted until his death.

The list of Wurm's papers and articles contains several with spectroscopic topics, including work on planetary nebulae, comets, and stellar atmospheres. Beside contributions to textbooks (*e. g.*, *Handbuch der Astrophysik*, Berlin 1930) he wrote two books, one on planetary nebulae and another on comets. In addition he published a *Monocromatic Atlas of the Orion Nebula* (26 sheets) with a later supplement of 20 sheets. Minor planet (1785) Wurm is named in his honor.

Christof A. Plicht

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Wyse, Arthur Bambridge

Born **Blairstown, Ohio, USA, 25 June 1909**
Died **over the Atlantic Ocean, off the New Jersey coast, 8 June 1942**

Arthur Wyse was best known for his analysis of the spectra of novae, especially Nova Aquilae 1918, which, he demonstrated, expanded at a nearly constant rate for more than 20 years. Wyse was the son of Reverend Charles and Celia Wyse, and received his degrees from the College of Wooster (AB: 1918), the University of Michigan (AM: 1931), and the University of California, Berkeley (Ph.D.: 1934). His doctoral thesis, under **Heber Curtis** at the Lick Observatory, was a study of the light curves of eclipsing binaries. He briefly held a Martin Kellogg Fellowship at Rochester University after completing his Ph.D.

In l935, Wyse was one of the first two new staff appointments made at Lick by **William Wright** upon succeeding **Robert Aitken** as director. In 1938/1939 Wyse collaborated with **Ira Bowen**, then visiting the Lick Observatory, on the spectra of planetary and gaseous nebulae. Wyse continued this research on his own until late 1941, when he joined the US Naval Reserve as a lieutenant.

Although Wyse was primarily an observational astronomer, he was also an able theoretician, as shown by his analysis of limb darkening in eclipsing binaries, and of the mass distribution and dynamics of the spiral galaxies M31 and M33 (the latter with **Nicholas Mayall**). But his best-known work was his study of the spectra of novae, including v603 Aql (Nova Aquilae 1918), HR Lyrae (1919), and EL Aql (1927), using archival Lick plates and v368 Aql (1936), using his own observations. His work on planetary and gaseous nebulae showed that they have similar compositions to each other, and probably also to those of the Sun and stars. He published a notable catalog of 270 emission lines observed in the spectra of 10 nebulae in 1942. In addition to the collaborations mentioned earlier, he guided **Daniel Popper** through his Lick thesis on spectrophotometry of CP Lac (Nova Lacertae 1936).

Wyse died as the result of an airship accident while on leave-of-absence from the Lick Observatory in naval service during World War II. As a result, Lick lost a very able astronomer, with wide interests in astrophysics, in the early stages of his scientific career.

John Hearnshaw

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X

Xenophanes of Colophon

Born **Colophon (near Selçuk, Turkey), *circa* 571 BCE**
Died **possibly (Sicily, Italy), *circa* 475 BCE**

Xenophanes' primary contribution to astronomy was in cosmology, and he is often remembered more as a theologian.

The dates of Xenophanes' life, particularly his birth, should not be taken as exact. There are some scholars who suggest an earlier date of 580 BCE for his birth. He was said to be the son of Dexias, and is considered the founder of the Eleatic School. It is known that early in his life he left Ionia for Sicily when the Persians took over Colophon. In Sicily, around 545 BCE, he worked at the court of Hiero, possibly as a wandering poet. He later departed for Magna Graecia (the Greek colonies in southern Italy), where he took up the profession of philosophy. Some scholarly sources suggest that he became an eminent Pythagorean scholar (though some dispute this), and thus it is likely that he spent some time in Crotona (Croton or Crotone), where **Pythagoras** had founded his religious school. It is also possible that he spent time in Siris, which had been colonized by Greeks from Colophon, his birthplace. Both Siris and Crotona were in Magna Graecia. Some (Robinson, 1968) suggest that he remained in Sicily until he died, but this is unlikely given his predilection for wandering as a poet. It is more likely that he died in Elea, based on the extent of the literature. His relationship with Pythagoras is something that is still not settled. Robinson claims Xenophanes predated Pythagoras in his philosophy (though the two were nearly the same age), but less reliable sources indicate otherwise.

Xenophanes made several important contributions to early physical and astronomical theories in addition to cosmology. He contributed to an understanding of the Earth in that he recognized that water was cycled from the sea to the clouds and from the clouds into rain, which cycled back to the sea. He also suggested a theory of the Sun, saying that the Sun actually came into being each day from small pieces of fire collected together. The Earth, Xenophanes said, was infinite and was not enclosed by air or by the heavens. He also said that there were innumerable suns and moons and that everything was made of earth. This last assertion does leave one to wonder whether he meant everything found on Earth, or if he included the heavenly bodies in the Earth; for, in the same passage, he mentions the development of the Sun from fire. He later said that the Sun and stars come from the clouds and that the Sun is actually made of ignited clouds. Rainbows also were supposedly made of clouds. In relation to his concept that there existed many suns and moons, Xenophanes developed a very abstract theory of eclipses.

Ian T. Durham

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Ximenes, Leonardo

Born **Trapani, (Sicily, Italy), 1716**
Died **Florence, (Italy), 1786**

Beginning in 1756, Sicilian Jesuit Leonardo Ximenes used a wall hole in the Duomo (Cathedral) of Florence to project the Sun onto the marble floor below. Doing so, he experimentally determined the rate-of-change for the obliquity of the ecliptic.

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Y

Yaḥyā ibn Abī Manṣūr: Abū ʿAlī Yaḥyā ibn Abī Manṣūr al-Munajjim

Flourished **Baghdad, (Iraq), *circa* 820**
Died **near Aleppo, (Syria), 830**

Yaḥyā ibn Abī Manṣūr was the senior astronomer/astrologer at the court of the ʿAbbāsid caliph **Ma'mūn**. He is well-known for his leading role in the earliest systematic astronomical observations in the Islamic world, which were carried out in Baghdad in 828–829, and for the astronomical handbook, *al-Zīj al-mumtaḥan*, that was written on the basis of these observations.

Yaḥyā was of Persian descent and originally named Bizīst, son of Fīrūzān. Since his father, Abū Manṣūr Abān, was an astrologer in the service of the second ʿAbbāsid caliph al-Manṣūr (754–775), we may assume that Yaḥyā spent his youth in Baghdad. His first known position was as an astrologer for al-Faḍl ibn Sahl, vizier of the Caliph Ma'mūn. After al-Faḍl was assassinated in February 818, Yaḥyā converted to Islam and adopted his Arabic name. He became a boon companion (Arabic: *nadīm*) of Ma'mūn, and is known to have made astrological predictions for the caliph on various occasions. He was also associated with the House of Wisdom and is mentioned as a teacher of the **Banū Mūsā**.

Ma'mūn strongly supported scientific activities, including the translation of Greek and Syriac scientific works into Arabic. In 828 and 829, he ordered astronomical observations to be carried out in the Shammāsiyya quarter of Baghdad with the purpose of verifying the parameters of the astronomical models of **Ptolemy** as found in his *Almagest* and *Handy Tables*. Yaḥyā became one of the most important persons involved in these observations together with **Jawharī**, **Sanad ibn ʿAlī**, and **Marwarrūdhī**.

The observational activities at Baghdad did not last for more than one and a half years. In that period basic observations of the Sun and the Moon were made, but a determination of all planetary parameters was not possible. Some specific values that were found are: 23° 33′ for the obliquity of the ecliptic (encountered only in the works of Yaḥyā and incidentally in those of his later contemporary **Ḥabash al-Ḥāsib**); a precession of the equinoxes of 1° in 66 Persian years (which may, however, have been influenced by Sasanian–Iranian measurements); a maximum solar equation of 1° 59′; and a maximum equation of center for Venus of 1° 59′. All four results constituted major improvements upon Ptolemy's outdated or incorrect values.

Yaḥya's name is associated with an astronomical handbook with tables dedicated to Ma'mūn. This work is known as *al-Zīj al-Ma'mūnī* or, more commonly, *al-Zīj al-mumtaḥan*, that is the *Verified Zīj* (Latin *Tabulae probatae*). A late recension of the *Zīj* is extant in the manuscript Escorial árabe 927, which contains, besides original material from Yaḥyā, numerous chapters, treatises, and tables of later date. In particular, we find material from the important 10th-century astronomers **Ibn al-Aʿlam**, **Būzjānī**, and **Kūshyār ibn Labbān**. Furthermore, there are various tables specifically intended for a geographical latitude of 36°, which corresponds to Mosul rather than to Baghdad. In 2004 the manuscript Leipzig Vollers 821 was recognized to be a recension of the *Mumtaḥan Zīj*. In some respects it is similar to the one in the Escorial library, but with fewer later additions. This copy has various insertions originating from **Battānī** and was apparently used in present-day southeastern Turkey.

Among the materials in the Escorial manuscript explicitly attributed to Yaḥyā are the tables for the lunar equation and the theory of solar eclipses. The latter is a typical mixture of Indian, Sasanian, and Hellenistic influences. The Ptolemaic table for the solar equation, which is also found in Ḥabash's *zīj*, may not be original, since a table of a more primitive nature is attributed to Yaḥyā in the 14th-century *Ashrafī Zīj*. Whereas the planetary equations were directly copied from the *Handy Tables*, the tables for the latitudes of the Moon and the planets are of a simple sinusoidal type and based on otherwise unknown parameters. A table with longitudes and latitudes of 24 fixed stars is indicated to be for the year 829 and derived from the observations made at Shammāsiyya.

It is not known with certainty whether the original *Mumtaḥan Zīj* was a work by Yaḥyā alone or a coproduction of the group of astronomers who were involved in the observations carried out on the order of Ma'mūn and who were referred to as *aṣḥāb al-mumtaḥan*, "authors of the verified (tables)." It is also possible that various of these astronomers wrote their own works with the title *Mumtaḥan Zīj*. Similarly, it is unclear what Ibn al-Nadīm (10th century), the earliest important biographer of Muslim scholars, meant by a "first" and "second" "copy" (Arabic: *nuskha*) of the work. In any case, the *Mumtaḥan Zīj* was very well-known and frequently quoted. **Thābit ibn Qurra** (second half of the 9th century) wrote a treatise on the differences between the *Mumtaḥan Zīj* and Ptolemy's astronomical tables, which is unfortunately lost.

Very little is known about other works by Yaḥyā. Ibn al-Nadīm mentions a *Maqāla fī ʿamal irtifāʿ suds sāʿa li-ʿarḍ Madīnat al-Salām* (Treatise on the determination of the altitude of [each] sixth of an hour for the latitude of Baghdad), as well as a *Kitāb*^{un} *yaḥtawī ʿalā arṣād lahu* (Book containing his observations) and *Rasā'il ilā jamāʿa fī al-arṣād* (Letters to colleagues concerning observations). A small astrological work by Yaḥyā entitled *Kitāb al-rujūʿ wa-'l-hubūṭ* (Book on retrogradation and descent) is extant in the very late manuscript 173 of Kandilli Observatory in Istanbul. It appears that Yaḥyā was also involved in the measurement of 1° on the meridian that was carried out on the order of Ma'mūn in the Sinjār plain (in northern Iraq). On the other hand, both the book *Fī al-ibāna ʿan al-falak* and a set of measurements of the obliquity made at Marv (mentioned by **Bīrūnī** in his geographical masterwork *Taḥdīd*) have been incorrectly attributed to Yaḥyā by modern authors; in fact, they are associated with the Tahirid Governor of Khurāsān, Manṣūr ibn Ṭalḥa (*circa* 870).

Yaḥyā died in the early summer of 830 during the first of Ma'mūn's expeditions against Tarsus in Asia Minor. He was buried in Aleppo, where his tomb could still be seen in the 13th century. Thus the astronomical observations carried out during the years 831 and 832 at the monastery of Dayr Murrān on Mount Qāsiyūn near Damascus and headed by Marwarrūdhī took place after Yaḥyā's death. A number of Yaḥyā's descendants were also boon companions of the ʿAbbāsid caliphs and well-known scholars. One of his four sons, Abū al-Ḥasan ʿAlī (died: 888), collected a huge library for al-Fatḥ ibn Khāqān, secretary of caliph al-Mutawakkil (847–861), where, among others, the famous astrologer **Abū Maʿshar** is known to have studied. Yaḥyā's grandson Yaḥyā ibn ʿAlī was a famous theorist of music. His great-great-grandson Hārūn ibn ʿAlī (died: 987) was an able astronomer and likewise author of a *zīj*.

Benno van Dalen

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Yaʿqūb ibn Ṭāriq

Flourished **Baghdad, (Iraq), 8th to 9th century**

Yaʿqūb ibn Ṭāriq is known as a contemporary and collaborator of the 8th-century scholars in Baghdad (particularly **Fazārī**) who developed from Greek, Indian, and Iranian sources the basic structure of Arabic astronomy. Works ascribed by later authors to Yaʿqūb include the *Zīj maḥlūl fī al-Sindhind li-daraja daraja* (Astronomical tables in the *Sindhind* resolved for each degree), *Tarkīb al-aflāk* (Arrangement of the orbs), and *Kitāb al-ʿilal* (Rationales [of astronomical procedures]). He is also said to have written a *Taqṭīʿ kardajāt al-jayb* (Distribution of the *kardaja*s of the sine [sine values]), and *Mā irtafaʿa min qaws niṣf al-nahār* (Elevation along the arc of the meridian), which may be related to or incorporated within one of his more general works. An otherwise unknown astrological work entitled *Al-maqālāt* (Chapters) is also attributed to Yaʿqūb by one (unreliable) source. None of the above works is now extant, and only the first three are known in any detail from later writings.

Yaʿqūb's *zīj* (handbook with astronomical tables), like that of Fazārī, was apparently based on the Sanskrit original of the *Zīj al-Sindhind*, translated by them in Baghdad in the 770s. (A highly embroidered 12th-century account of Yaʿqūb's involvement in this translation is given by **Abraham ibn ʿEzra**.) Also like Fazārī's, the surviving fragments of Yaʿqūb's *zīj* are a heterogeneous mix from different traditions. For example, the mean motion parameters are Indian, as is the rule for visibility of the lunar crescent; the calendar is Persian;

and the Indian sunrise epoch for the civil day appears to have been converted to the Greek-inspired noon epoch by the simple expedient of moving the prime meridian 90° (or 1/4th day) eastward from the usual location of Arin (Ujjain).

The *Tarkīb al-aflāk* was an early work on the topic that became known as *hay'a* or cosmography (*i. e.*, the arrangement, sizes, and distances of the celestial orbs). Yaʿqūb's work apparently stated the orbital radii and sizes of the planets, as well as rules for determining accumulated time according to techniques in Sanskrit treatises. **Bīrūnī** in the 11th century mentioned the *Tarkīb* as the only Arabic source using the Indian cosmographic tradition (although at least some of the same values were known from other *zīj*es); if his descriptions of some of Yaʿqūb's rules are accurate, Yaʿqūb did not always fully understand or correctly interpret the Indian procedures.

It is also from Bīrūnī that we derive our knowledge of the *Kitāb al-ʿilal*, an early representative of the genre of "rationales" or "causes" treatises that undertook to provide mathematical explanations of the computational rules in *zīj*es. All of Bīrūnī's references to this work are contained in his *al-Ẓilāl* (On shadows), so they are limited to trigonometric procedures using gnomon shadows in calculations of time and location. By this time, evidently, Yaʿqūb's works were valued primarily for the information they provided about early influences from the Indian tradition, many of which were replaced in later Islamic astronomy by predominantly Ptolemaic techniques.

Kim Plofker

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Yasuaki

❯ **Asada, Goryu**

Yativṛṣabha

Flourished **Prākrit, Jadivasaha, (India), 6th century**

Little is known about Yativṛṣabha. He was a Jain monk who studied under Ārya Maṅkṣu and Nāgahastin. He composed, along with other traditional Jain works, the *Tiloyapaṇṇattī* (in Sanskrit, *Trilokaprajñapti* or Knowledge on the three worlds), a work on Jain cosmography. This work describes the construction of the Universe expressed in specific numbers; for example, the diameter of the circular Jambu continent, upon which India is located, is 100,000 yojanas and its circumference is 316,227 yojanas, 3 krośas, 128 daṇḍas, 13 aṅgulas, 5 yavas, 1 yūkā, 1 ṛikṣā, 6 karmabhūmivālagras, 7 madhyabhogabhūmivālagras, 5 uttama bhogabhūmivālagras, 1 rathareṇu, 3 trasareṇus, 2 sannāsannas, and 3 avasannāsannas, plus a remainder of 23213/105409. Yativṛṣabha also gives formulas for computing the circumference (C) and the area (A) of a circle having a diameter of d:

$$C = \sqrt{10d^2},\ A = C \cdot \frac{d}{4}$$

Setsuro Ikeyama

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Yavaneśvara

Flourished **(western India), 149/150**

Yavaneśvara translated a Greek astrological text (probably composed in Alexandria in the 1st half of the 2nd century BCE) into Sanskrit prose in 149/150 at Ujjayinī, the capital of the Western Kṣatrapas, during the reign of Rudradāman I. (Yavaneśvara, literally "lord of the Greeks," was probably a title for leaders of Greek merchants in Western India, *circa* 78–390, and not a proper name.) This translation, which is no longer extant, was versified and titled *Yavanajātaka* by **Sphujidhvaja** in 269/270. Verse 61 of Chapter 79 of this work runs:

> Yavaneśvara, who sees the truth coming from the brightness of the sun and speaks unblamable words, conveyed this treatise on horoscopy for the local authority in primitive words.

The work of Yavaneśvara became one of the major sources for Indian horoscopy.

Setsuro Ikeyama

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Yixing

Born **Changle (Nanle, Henan), China or Julu (Hebei), China, 683**
Died **(Shaanxi), China, 727**

Yixing was a Chinese Buddhist monk and astronomer during the Tang dynasty. Yixing was his Buddhist name; his secular name was Zhang Sui.

In 717, Yixing received a call from Emperor Xuanzong, and he moved to Chang'an, then the capital. In 721, at the emperor's request Yixing started a project to make a new calendar. Yixing made an armillary sphere with his colleague Liang Lingzan around 724. From 724 onward Yixing conducted astronomical observations at several places all over China with his colleague Nangong Yue. In 725, Yixing made a water-driven celestial globe with Liang Lingzan. After these preparations, Yixing started to compile the new calendar, and completed the draft of the Dayan calendar in 727. As Yixing died the same year, Zhang Shui and Chen Xuanjing edited Yixing's draft, and the Dayan calendar was officially promulgated after 729.

During the Sui (581–618) and Tang (618–907) dynasties, several calendars were constructed. The Huangji calendar (600) of Liu Zhuo (544–610) was not officially used, but was an excellent calendar in which the inequalities corresponding to the equations of the centers of the Sun and the Moon and the precession of the equinoxes were all considered. In it second-order interpolation was used for the first time in China. The Linde calendar (665) of **Li Chunfeng** (602–670) is another well-known calendar of the time. (Li Chunfeng is also famous for his armillary sphere.) The Dayan calendar (727) of Yixing was one of the best calendars of the Tang dynasty. The Xuanming calendar (822) of Xu Ang is another famous one, in which the method of prediction of eclipses was improved. The Chongxuan calendar (892) of Bian Gang deserves note as well.

The Tang dynasty was the period when Indian astronomy was introduced to China. Some information on Indian astronomy might have reached China during the later Han dynasty. A Buddhist text containing knowledge of Indian astrology and astronomy, the *Śārdūlakarṇa-avadāna*, was translated into Chinese in the 3rd century during the Three Kingdoms period. During the Tang dynasty, a detailed work of Indian mathematical astronomy, the *Jiuzhi li* (Jiuzhi calendar; 718), was composed in Chinese by the Indian astronomer (resident in China since his grandfather's time) Qutan Xida (Chinese transliteration of Gotama-siddartha in Sanskrit), and was included in his ([*Da*]*Tang*) *Kaiyuan zhanjing*. In the 8th century, a Chinese version of Indian astrology, the *Xiuyao jing*, was composed in Chinese by Bukong, an Indian monk (whose Sanskrit name was Amoghavajra; 705–774). Amoghavajra was a disciple of Vajrabodhi, with whom Yixing also studied. Yixing certainly had knowledge of Indian astronomy, but made his Dayan calendar in Chinese traditional style.

Yixing and Liang Lingzan made an armillary sphere called *Huangdao youyi* (Instrument with a movable ecliptic circle) around 724. In this instrument, the ecliptic circle could be moved in accordance with the precession of the equinoxes. It also had a movable circle for the lunar orbit. With this instrument, Yixing observed stars, particularly the 28 lunar mansions, and (comparing with previous observations) measured the change of their polar distance and right ascension (*i. e.*, the change due to the precession of the equinoxes). Yixing and Liang Lingzan also made a water-driven celestial globe in 725. Besides the celestial globe itself, the device had two wooden figures that struck a drum and gong automatically.

From 724 to 725, Yixing and Nangong Yue conducted astronomical observations at 13 different places from about 51° N to about 18° N. They observed the altitude of the North Celestial Pole, the length of the gnomon shadow at solstices and equinoxes, and the length of daytime and nighttime at solstices.

In regard to astronomical theory, the Dayan calendar of Yixing is one of the best calendars from China. It has several features of significance: For example, the inequality corresponding to the equation of the center of the Sun was discovered by **Zhang Sixun** in the sixth century for the first time in China. For this inequality, Yixing gave the values for 24 seasonal nodes in a year, which were divided according to the Sun's angular movement. Here, Yixing used second-order interpolation with unequal steps of argument for the first time in China. For the inequality corresponding to the equation of the center of the Moon, which was discovered during the later Han dynasty in the 1st century, Yixing used the second-order interpolation with equal steps of argument invented by Liu Zhuo (542–608) during the Sui dynasty.

An attempt to predict lunar eclipses was first made in the Santong calendar of Liu Xin (died: 23) at the end of the former Han dynasty, and the basis of the standard system of the prediction of solar and lunar eclipses was established in the Jingchu calendar (237) of Yang Wei in the Three Kingdoms period. For the prediction of solar eclipses, Yixing considered the lunar parallax at different places. Although his method was not perfect, it was a big step forward. The method of predicting eclipses was further developed in the Xuanming calendar (822) of Xu Ang.

Yixing also improved the calculation of the positions of the five planets, and used a type of interpolation in which the third difference is used, although it was not interpolation of the third order.

Another Yixing contribution was a device to calculate the length of the gnomon shadow and the length of daytime and nighttime in different seasons at different places. For this purpose, Yixing made a table of the gnomon shadow for every Chinese degree (*du*), from 0 to 81, of the Sun's zenith distance. (One Chinese *du* is the angular distance on the celestial sphere through which the Sun moves in one day.) This Yixing table is the earliest tangent table in the world.

For the transformation of spherical coordinates, the graphical method on the celestial globe had been used since the later Han dynasty. An arithmetical method was started in the Huanji calendar (600) of Liuzhuo, and Yixing also used the arithmetical method. In this method, the difference between right ascension and polar longitude (longitude of the requisite hour circle on the ecliptic) was assumed to be a linear function in a quadrant, and the difference was given by a table.

The Dayan calendar of Yixing was introduced to Japan, and was officially used there from 746 to 857.

Alternate names

I-Hsing
Seng Yixing
Yixing Chanshi

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Yixing Chanshi

➔ **Yixing**

Young, Anne Sewell

Born **Bloomington, Wisconsin, USA, 2 January 1871**
Died **Claremont, California, USA, 15 August 1961**

Anne Young, an outstanding teacher of astronomy, was one of the eight founders of the American Association of Variable Star Observers [AAVSO], and for many years contributed observations of variable stars and sunspots to that organization.

The niece of astronomer **Charles Young**, she received B.L. and M.S. degrees from Carleton College, and a Ph.D. in 1906 from Columbia. Recognized as an outstanding teacher, she taught astronomy for 3 years (1895–1898) at Whitman College, and then for 37 years (1899–1936) at Mount Holyoke College; among her students there who distinguished themselves in astronomy was **Helen Sawyer Hogg**.

Katherine Bracher

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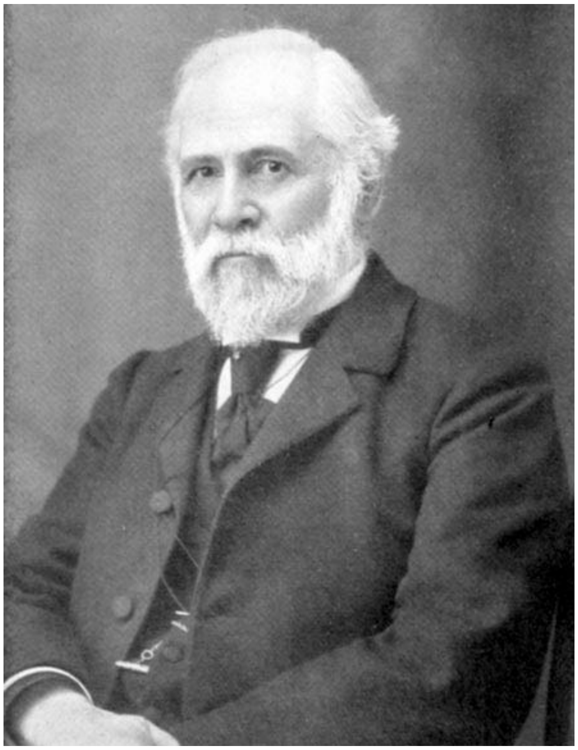
Young, Charles Augustus

Born **Hanover, New Hampshire, USA, 15 December 1834**
Died **Hanover, New Hampshire, USA, 3 January 1908**

Charles Young was a pioneer in solar physics who identified properties of the chromosphere.

Young's father, Ira Young, and grandfather, Ebenezer Adams, were both professors of mathematics and natural philosophy at Dartmouth College, Hanover, New Hampshire, where Young graduated in 1853. He then taught Latin and Greek for 2 years at Phillips Academy in Andover, Massachusetts. Enrolling at the Andover Theological Seminary, Young first contemplated missionary work, but in 1857 accepted a position at Western Reserve College in Hudson, Ohio as professor of natural philosophy and astronomy. That same year, he married Augusta S. Mixer; the couple later had three children. During the Civil War (1862), Young served for 4 months in the 85th regiment of Ohio volunteers. In 1866, he returned to Dartmouth College to assume the position held by his father. But when promised a much larger telescope (a 23-in. refractor) by Princeton University in 1877, Young accepted their offer and spent the remainder of his career as director of Princeton's Halsted Observatory.



Young worked chiefly in visual spectroscopy, and observed solar prominences without an eclipse, by using the spectroscope as a monochromator. During the 7 August 1869 total solar eclipse, Young, in collaboration with **William Harkness**, discovered a green line in the coronal spectrum without a known counterpart in terrestrial laboratory spectra. It took solar physicists over 60 years to realize that the green line belonged to a highly ionized state of iron, indicative of the million-degree temperature of the solar corona. During the 22 December 1870 eclipse, Young observed the "flash spectrum" of the chromosphere and explained its occurrence as due to a "reversing layer" above the Sun's photosphere. At that same eclipse, he also captured the first photograph of a solar prominence.

In 1876, Young used a grating spectroscope to make one of the earliest measurements of the Sun's rotation *via* the Doppler shift. He led other eclipse expeditions around the world (in 1878, 1887, and 1900) and to high mountain altitudes to make spectroscopic observations of the Sun's outer atmosphere. Many of these results were collected in his textbook, *The Sun* (1st edition, 1881), which influenced the next generation of American astrophysicists. Young's teaching and laboratory work turned the Princeton campus into a highly regarded training ground for future spectroscopists. His final scientific paper suggested that "atomic" (*i. e.*, nuclear) energy associated with radioactivity might one day explain the Sun's enormous energy production.

Young saw no conflict between scientific research and religious faith, regarding the "dignity of the human intellect" as the "offspring, and measurably the counterpart, of the Divine" (*Manual of Astronomy*). He was an effective and widely sought public speaker on science and astronomy. Young delivered the keynote address at the dedication of **George Hale**'s Kenwood Physical Observatory at Chicago in 1891. Notable students of Young (from Dartmouth and Princeton) included **Edwin Frost** and **Henry Norris Russell**. One of the most widely used textbooks of the early 20th century, written by Russell, **Raymond Dugan**, and **John Stewart**, was a revision of Young's *Manual of Astronomy*.

Young was awarded numerous honorary degrees and prizes, including the Janssen Medal of the French Academy of Sciences (1891). He served as president of the American Association for the Advancement of Science (1884) and was a member of the National Academy of Sciences, the American Philosophical Society, and the Royal Astronomical Society of Great Britain. Due to declining health, Young retired from Princeton in 1905 and moved back to his native Hanover.

Fathi Habashi

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Yūnus

➤ **Ibn Yūnus: Abū al-Ḥasan ʿAlī ibn ʿAbd al-Rahman ibn Aḥmad ibn Yūnus al-Ṣadafī**

Z

Zach, János Ferenc [Franz Xaver] von

Born **Pozsony (Bratislava, Slovakia), 13 June 1754**
Died **Paris, France, 2 September 1832**

Hungarian-born astronomer and geodetic surveyor, Baron János von Zach is best remembered for his organizational services. Zach was born to a noble family, son of József Zách and Klára Szontágh. He studied physics in Pest, Hungary, and finished his studies in the military academy in Vienna. In the second half of the 1770s, he taught mechanics at the University of Lemberg (now Lyio, Ukraine). When the university ceased operations, Zach moved to Paris (1780) and then to London (1783).

There, Zach made his acquaintance with several leading astronomers, including **Joseph de Lalande**, **Pierre de Laplace**, and **William Herschel**, as well as rich patrons of astronomy. With their influence, Zach was granted an astronomer's position by Duke Ernst II of Saxe-Gotha-Altenburg. Commissioned to plan and build a new observatory, he founded and became director of the Seeberg Observatory (near Gotha) from 1786 to 1804. Research began there in 1792 with instruments made by Jesse Ramsden. After the death of Ernst II in 1804, Zach was disgraced and left Gotha with Duchess Marie Charlotte Amalie (1751–1827), widow of Ernst II. They lived in various places and finally settled in Genova (Italy) in 1815. That year, he founded the Capodimonte Observatory in Naples, Italy. From 1827 on, Zach lived in Paris.

Zach's main astronomical contribution was the foundation of the first international astronomical periodical, the *Monatliche Correspondenz zur Beförderung der Erd- und Himmelskunde*, which was published in 28 volumes between 1800 and 1813. His previous journal, *Allgemeine Geographische Ephemeriden*, published between 1798 and 1799, covered both astronomy and geography. When Zach settled in Italy, he founded and edited a new journal, *Correspondence Astronomique*, which appeared in 13 volumes between 1818 and 1825. These journals enabled contemporary astronomers to distribute their observational results and newly developed mathematical methods in a very efficient way.

He regularly received guest astronomers in Seeberg, site of the first international meeting of astronomers, organized by Zach in 1798. He founded the first international association of astronomers, sometimes called the astronomical police, with the aim of launching an observational campaign for searching the planet missing between Mars and Jupiter, according to the Titius–Bode law. Members of this group were Ferdinand Adolf von Ende, **Johann Gildemeister**, **Karl Harding**, **Heinrich Olbers, Johann Schröter** (president), and Zach (secretary). Their Astronomische Gesellschaft is not identical with the still existing Astronomische Gesellschaft, founded in 1863. The first-discovered minor planet, (i) Ceres, was found by **Giuseppe Piazzi** just before Zach's group began their coordinated observations. Based on calculations by his pupil, **Carl Gauss**, Zach rediscovered the temporarily lost Ceres in December 1801, though this recovery is sometimes erroneously attributed to Olbers.

Zach's research activity also included observations of Mars during its opposition of 1790, and observations of the transits of Mercury in 1802 and 1805. He published corrected tables of solar motion (1792) and tables for aberration (1813).

Zach was a fellow of the Royal Society (1804) and an honorary member of the Hungarian Academy of Sciences (1832). A lunar crater and minor planet (999) Zachia are named for him.

László Szabados

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Zacut: Abraham ben Samuel Zacut

Born **Salamanca, (Spain), probably 1452**
Died **Damascus, (Syria), probably 1515**

Abraham Zacut was an important Jewish astronomer who contributed to observational astronomy, astronomical tables, and our historical knowledge of astronomy in Spain. Zacut came from a family originally from France; however, the evidence indicates that he was born in Salamanca, and spent his early years there as a pupil of Isaac Aboab, from whom he received the extensive knowledge that would later make him famous. Although professionally a doctor, Zacut's fame came from his works in astronomy.

During his lifetime, Zacut maintained relationships with several notable figures, including Don Juan de Zúñiga, the last Master of the Order of Alcántara (*Maestre de la Orden de Alcántara*), and the Bishop of Salamanca, Gonzalo de Vivero, to whom he dedicated his most famous astronomical work. When Bishop Vivero died in 1480, Zacut lost his protector in Salamanca and moved to the court of Don Juan de Zúñiga for whom he produced the following works: *Tratado breve de las influencias del cielo* (Short treatise on the influence of the heavens) and *De los eclipses del sol y la luna* (On solar and lunar eclipses). We know that Zacut was in Lisbon on 9 June 1493, working for Juan II of Portugal. It is logical to assume that he moved to this city when the Jews were expelled from Spain following the order of the Catholic kings in 1492. Zacut also worked for the brother of King Manuel I, who is said to have sought Zacut's advice for Vasco de Gama's trip around Africa, for which Zacut gave a favorable opinion. When in 1496 King Don Manuel ordered the Jews expelled from Portugal, Zacut fled Portugal and moved to Tunisia, where he was welcomed by a large Jewish colony. He lived in Carthage for several months, giving lessons in subjects for which his expertise was renowned. He eventually moved to the Ottoman lands and died, probably in 1515 although a death date of 1522 has also been suggested.

It is not clear whether or not Zacut taught at the University of Salamanca. However, he was in contact with and influenced some of the professors of astrology there. For example, Juan de Salaya, who was a professor of astrology from 1464 to 1469, translated Zacut's work titled *La Compilación Magna* (ha-*Hibbur ha-gadol* or The magnus compilation) from Hebrew into Spanish. The Latin translation, known as *Almanach Perpetuum*, was made by José Vizinho and first published in Leira in 1496. It became essential for the development of Spanish and Portuguese navigation at the end of the 15th century. The Spanish translation made Zacut famous due to its influence on his contemporaries.

La Compilación Magna was commissioned by Zacut's protector, Gonzalo de Vivero. Indeed the bishop left instructions regarding Zacut in his will as follows:

> …to deliver to the Jew Abraham, astrologist, five hundred maravedises and ten measures of grain, and instructed that certain works which were in Romance, written by the mentioned Jew, should all be published in a volume together with his other books in his [*i. e.* the bishop's] church, because it is worthy to understand the tables made by the mentioned Jew.

This volume could be Incunable 176, presently kept at the Salamanca University Library, which contains the Spanish translation of *La Compilación Magna* that was dictated by Zacut to the translator Juan de Salaya.

La Compilación Magna is a collection of astronomical tables with rules (canons) that served several purposes. The tables were calculated for the meridian of Salamanca for the *radix* year 1473. The first part of the collection contains the rules in 19 chapters, a number Zacut uses because he considers it a golden number, following the indication of **Maimonides**. In those chapters he first analyzes the positions of the Moon and the Sun, their movements, circumstances, and eclipses, and then moves to the astrological houses and to the ascendant. He also provides the longitudes and latitudes of the main cities; finally he devotes a chapter to the fixed stars. In the second part of the canons, Zacut explains the circumstances of the other planets (Saturn, Jupiter, Mars, Venus, and Mercury) and devotes one chapter to the Jewish, Christian, Islamic, and Persian calendars. This second part comes to a close with Chapter 19, where he explains the movements of the seven planets and of the lunar node (Dragon Head). After the canons, he gives the tables for the material discussed in these 19 chapters. The structure of the tables is influenced by Jacob Poel (Bonet Bonjorn), an intermediary who connected the work of **Gersonides** and Zacut. More than 50 manuscripts are known of these tables, of which we should particularly note MS Sassoon 823 for its detailed "representation" of its catalog of stars. In addition to mentioning Bonet Bonjorn, whom the translator Salaya refers to by his Hebrew name Jacob Poel (Po 'el meaning "the artisan"), Zacut mentions the Jewish scholar Yehuda ben Aser. There are also references to the tables and calendar of King **Alfonso X**.

The canons of the *Almanach perpetuum* also exist in another Spanish version that was made by the same José Vizinho who made the Latin translation. A copy of this Spanish version is kept in an *incunabulum* of the Colombin Library of Seville's Cathedral. It consists of 23 chapters dealing with the ascendants of the 12 houses, explanations of the positions of the Sun and the Moon and their eclipses, the places and movements of the planets, and a reference in the last chapter to an "animodar."

Zacut's empirical interests are indicated by his observation in 1474 of the Moon covering the star of the spike in Virgo's hand, when this constellation was approximately in the middle of the sky. Other astronomical observations attributed to him are an occultation of Venus by the Moon in July 1476, and a total solar eclipse in June 1478.

Cirilo Flórez Miguel

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Zanotti, Eustachio

Born **Bologna, Enilia-Romagna, (Italy), 27 November 1709**
Died **Bologna, Enilia-Romagna, (Italy), 15 May 1782**

Eustachio Zanotti was a versatile observer, professor, and observatory director in Bologna. The son of Gian Pietro Zanotti and Costanza Gambari, he came from a family known for its interest in the arts, humanities, and science. His early studies were at the Jesuit School. He was exposed to Bologna's most illustrious scientists, including the Manfredi and Beccari families, who were often guests at his house, and his uncle, Francesco Maria Zanotti, was president of the Istituto delle Scienze. Zanotti attended lessons at the institute and, under the guidance of **Eustachio Manfredi**, he became enthralled with astronomy and was appointed as Manfredi's assistant at the observatory in 1719.

On 22 August 1730 Zanotti graduated from the University of Bologna with a degree in philosophy. In 1738, after presenting an essay on the Newtonian theory of light, he embarked on his university career as professor of mechanics. That year, he discovered two comets to which he attributed a parabolic orbit. Following Manfredi's death the following year, Zanotti was appointed to the university chair of astronomy. Only a year before, the chair *ad Mathematicam*, established in 1569, was replaced by five other scientific disciplines, including astronomy. The program was also modified to permit the teaching of heliocentric theories (although it would not be until 16 April 1757 that the Sacred Congregation of the Index would permit the free circulation of such ideas).

Zanotti was also appointed professor of astronomy at the Istituto delle Scienze – then still independent of the university – in 1739. During his years of teaching, he continued to publish the *Ephemerides* started by Manfredi, compiling three volumes covering the years from 1751 to 1774. A fourth volume was published posthumously by his successor, Petronio Matteucci.

The modern instruments that Manfredi had ordered from London in 1738 were finally brought to Bologna in 1741: a mural quadrant with a radius of 1.2 m, a transit instrument with a focal length of 1 m, a movable quadrant, and a small reflecting telescope (built by English craftsman Jonathan Sisson and now exhibited at the Astronomical Museum of the Department of Astronomy at the University of Bologna, in the same rooms in which the astronomers used them). Because of the work required to restructure the room of meridian observations at the observatory and to put the instruments into operation and adjust them, they could not be used until 1749.

Zanotti worked with his assistants Giovanni Angelo Brunelli, who would later become mathematician to the king of Portugal, and Matteucci, conducting countless observations of the Sun, Moon, planets, and comets, and compiling a catalog of 446 stars, mostly in the zodiac. Their goal was to add to the knowledge of celestial motion and use lunar occultations to calculate more accurate terrestrial coordinates. This catalog – published by Zanotti in the reprint of Manfredi's *Introductio in Ephemerides* – also can be considered one of the first star catalogs drawn based on modern criteria. To calculate the positions of the stars, it considered not only the precession of the equinoxes but also the effects of annual aberration, discovered a short time before by **James Bradley** and confirmed by Manfredi. Moreover, the results were supplemented with a more accurate determination of the latitude of Bologna (estimated at 44° 29′ 54″, just 1.2″ more than the actual figure) and the γ point, or the intersection between the Equator and the ecliptic, corresponding to the vernal equinox.

Zanotti's other main observations include lunar occultation of stars, lunar eclipses, solar eclipses, numerous comets (including comet 1P/Halley in 1759), and the transits of Mercury and Venus across the solar disk. In 1750 the Académie des sciences invited him to participate in an international research project to measure the lunar parallax, and he provided some of the most accurate observations.

In 1760, Zanotti was moved to the chair of hydrometry, and the Bologna government asked him to oversee the construction of a number of navigable canals. In 1776, he restored the meridian line in the church of San Petronio, constructed by **Giovanni Cassini** in 1655. The meridian had lost its original position because the ground had sunk, and there were depressions in the floor caused by earthquakes. As a result, the gnomonic hole on the roof of the church had shifted. Zanotti described this restoration work in the book *La meridiana del Tempio di San Petronio rinnovata l'anno 1776*. He also published a treatise, *Trattato teorico – pratico di prospettiva*, which was studied widely during the period. It was reprinted in 1825 with Zanotti's biography as a foreword. The biography was written by one of his collaborators, Luigi Palcani Caccianemici, who asserted that Zanotti had also studied the variability of stellar brightness, although none of these observations are reported in his works.

In 1778, Zanotti took his uncle's place as the president of the Istituto delle Scienze. His epitaph can still be seen in the church of Santa Maria Maddalena.

Zanotti's manuscripts and astronomical logbooks are in the Historical Archive of the Department of Astronomy, University of Bologna.

Fabrizio Bònoli

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Zanstra, Herman

Born **Heerenveen, the Netherlands, 3 November 1894**
Died **Haarlem, the Netherlands, 9 October 1972**

Dutch astrophysicist Herman Zanstra devised the method that bears his name, for determining the temperatures of stars powering emission-line nebulae. He was educated at the technical college in Delft, graduating as a chemical engineer in 1917. After teaching at the same college and the Delft secondary school, Zanstra went to the University of Minnesota in 1921 to work as an instructor in physics, and obtained his Ph.D. from the university in 1923. In his thesis he investigated August Föppl's hypothesis that the angular momentum of the Universe about its center of mass is zero.

Zanstra then had a series of short appointments at universities in Chicago, Hamburg, and Pasadena (California, USA); the University of Washington; and Imperial College London. He spent the summer of 1927 at the Dominion Astrophysical Observatory in Victoria, Canada, returning to the Netherlands in 1931 as an assistant at the University of Amsterdam. Zanstra became a Radcliffe

Travelling Fellow in 1937, spending time in Oxford, England, and later at the Radcliffe Observatory in Pretoria, South Africa. He could not return to Europe because of the war and so taught physics at Howard College, Durban, from 1942 to 1946. In 1946 Zanstra was appointed professor of astronomy at the University of Amsterdam, where he remained until his retirement in 1961.

After completing his thesis, Zanstra began work on the excitation of gaseous nebulae. He realized that the primary mechanism for a hot star to excite a nebula is the photoionization of hydrogen and its subsequent recombination. He assumed that all stellar photons with wavelengths shorter than the Lyman limit would be absorbed and that the recombinations would give the Balmer lines and continuum. Each recombination would give one Balmer photon, so that measurement of the total Balmer emission would give a good estimate of the ultraviolet emission from the star, and this combined with the visible stellar radiation would give an estimate of the temperature of the star. The result was 34,000° K for O-type stars. Subsequently Zanstra studied planetary nebulae, and showed that their central stars had temperatures up to 150,000° K. In other works, Zanstra:

(1) suggested that the forbidden lines are excited by electron collisions;
(2) estimated the nebular distances and radii and their expansion velocities;
(3) modeled nebular expansion due to radiation pressure;
(4) suggested that lines and bands in cometary spectra are excited by resonance and fluorescence of the solar radiation in the cometary gases;
(5) made studies of Wolf–Rayet stars; and
(6) determined the density of a solar prominence.

He received the Gold Medal and George Darwin Lectureship of the Royal Astronomical Society in 1961. Minor planet (2945) was named for Zanstra.

Roy H. Garstang

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Zarqālī: Abū Isḥāq Ibrāhīm ibn Yaḥyā al-Naqqāsh al-Tujībī al-Zarqālī

Died **Córdova, (Spain), 15 October 1100**

According to his biographer Isḥāq Israeli, Zarqālī was a renowned instrument maker in Toledo, where he taught himself astronomy. He worked for **Ṣāʿid al-Andalusī** and was a leading figure among Ṣāʿid's group of astronomers. An anonymous Egyptian 14th-century source (*Kanz al-yawāqīt*, Leiden Universiteitsbibliotheek, MS 468) quotes a passage from Ṣāʿid's lost work entitled *Ṭabaqāt al-ḥukamā'*, in which it is stated that Zarqālī constructed an astronomical instrument, called *al-zarqāla*, for al-Ma'mūn (1043–1075), the ruler of Toledo, in the year 1048/1049. It also says that Zarqālī wrote a treatise of 100 chapters on its use. Zarqālī left Toledo between 1081, the beginning of the reign of al-Qādir, and 1085, the date of the conquest of the city by Alfonso VI. He settled in Córdova, where he was protected by al-Muʿtamid ibn ʿAbbād (1069–1091), ruler of Seville.

There are many variations of the name of Zarqālī, known as Azarquiel in Latin. According to the *Ṭabaqāt al-umam* of Ṣāʿid al-Andalusī, he was known as *walad al-Zarqiyāl*, from whence came the Hispanicized form *Azarquiel*. The 13-century biographer al-Qifṭī maintains the expression *walad al-Zarqiyāl* in his *Akhbār al-ʿulamā" bi-akhbār al-ḥukamā'*. Other readings quoted in Andalusian sources are al-Zarqālluh, al-Zarqāl, or Ibn Zarqāl; readings such al-Zarqāla and al-Zarqālī (sometimes al-Zarqānī) seem to be classicized Eastern forms.

In his *Jāmiʿ al-mabādi' wa-'l-ghāyāt fī ʿilm al-mīqāt*, an encyclopedic work on astronomy, **Abū al-Ḥasan ʿAlī al-Marrākushī** (13th century) states that Zarqālī was making observations in Toledo in 1061. This testimony is confirmed by **Ibn al-Hā'im al-Ishbīlī** (flourished: 1204/1205) in his *al-Zīj al-kāmil fī al-taʿālīm*, who attributes to Zarqālī 25 years of solar observations and 37 years of observations of the Moon. Al-Qifṭī says that his observations were used by **Ibn al-Kammād**.

One can generally classify the contents of Zarqālī's work under four main categories: astronomical theory, astronomical tables, magic, and astronomical instruments.

The following four works by Zarqālī deal with astronomical theory: (1) There is a treatise on the motion of the fixed stars, written *circa* 1084/1085 and extant in Hebrew translation. It contains a study of three different trepidation models, in the third of which variable precession becomes independent of the oscillation of the obliquity of the ecliptic. (2) There is a lost work summarizing 25 years of solar observations, probably written *circa* 1075–1080. Its contents are known through secondary sources, both Arabic and Latin. The title was either *Fī sanat al-shams* (On the solar year) or *al-Risāla al-jāmiʿa fī al-shams* (A comprehensive epistle on the Sun). In this work Zarqālī established that the solar apogee had its own motion (of about 1° in 279 Julian years) and devised a solar model with variable eccentricity that became influential both in the Maghrib and in Latin Europe until the time of **Nicolaus Copernicus**. (3) There is an indirect reference to a theoretical work entitled *Maqāla fī ibṭāl al-ṭarīq allatī salaka-hā Baṭlīmūs fī istikhrāj al-buʿd al-abʿad li-ʿUṭārid* (On the invalidity of **Ptolemy**'s method to obtain the apogee of Mercury) mentioned by **Ibn Bājja**. (4) There is a reference in Ibn al-Hā'im's work to Zarqālī's lost writing (*bi-khaṭṭ yadi-hi*, in his own hand) describing a correction to the Ptolemaic lunar model. Ibn al-Hā'im understands this correction as a result of the displacement of the center of the lunar mean motion in longitude to a point on a straight line linking the center of the Earth with the solar apogee, and at a distance of 24′. This model met with some success, for we find the same correction in later Andalusian (Ibn al-Kammād) and Maghribī (**Ibn Isḥāq**, **Ibn al-Bannā'**) *zīj*es, although restricted to the calculation of eclipses and the New Moon. It appears also in the Spanish canons of the first version of the *Alfonsine Tables* and in a

Provençal version of the tables of eclipses of **Gersonides**, although in these tables the amount is given as 29′ (either a copying error or a new estimation).

There are two works by Zarqālī dealing with astronomical tables: (1) The *Almanac* is preserved in Arabic, Latin, and in an Alfonsine translation. It is based on a Greek work calculated by a certain Awmātiyūs in the 3rd or 4th century, although the solar tables seem to be the result of the Toledan observations. Its purpose is to simplify the computation of planetary longitudes using Babylonian planetary cycles (*goal years*). (2) The *Toledan Tables* are known through a Latin translation. They seem to be the result of an adaptation of the best available astronomical material (*i. e.*, **Khwārizmī** and **Battānī**) to the coordinates of Toledo that was made by a team led by Ṣāʿid and in which Zarqālī seems to have been a prominent member. The mean-motion tables are original and are the result of observations. Ṣāʿid does not mention these tables although they had been completed before the writing of the *Ṭabaqāt* in 1068.

The only known magical work by Zarqālī is entitled *Risāla fī Ḥarakāt al-kawākib al-sayyāra wa-tadbīri-hi* (On the motions and influences of planets), which is a treatise on talismanic magic using magic squares to make talismans. It is preserved in two Arabic manuscripts, which contain two different versions of the text. There is also a third one summarized in a Latin translation.

Finally, Zarqālī has several works on astronomical instruments: (1) There is a treatise on the construction of the armillary sphere, which is preserved in an Alfonsine–Castilian translation. The original Arabic has not survived. (2) There are two treatises on the construction (*circa* 1080/1081) and use (*circa* 1081/1082) of the equatorium, dedicated to al-Muʿtamid. Zarqālī's equatorium differs from the earlier Andalusian model designed by **Ibn al-Samḥ** (*circa* 1025/1026) in that it is an independent instrument that represents all the planetary deferents and related circles on both sides of a single plate, while a second plate bears all the epicycles. Mercury's deferent is represented as an ellipse. (3) Marrākushī attributes to Zarqālī a sine quadrant with movable cursor (*majarra*), which is a graphic scale of solar declination with the solar longitude as argument. It is similar to the quadrant *vetustissimus*, although in this quadrant the argument used is the date of the Julian year. (4) There are two treatises on two variants of the same astronomical universal instrument (*al-ṣafīḥa al-mushtaraka li-jamīʿ al-ʿurūḍ*): A 100-chapter treatise on the use of the *ṣafīḥa* (plate), called the *zarqāliyya*, and another treatise of 60 chapters on the use of the *ṣafīḥa shakkāziyya*. In both instruments the stereographic equatorial projection of the standard astrolabe is replaced by a stereographic meridian projection onto the plane of the solstitial colure. In fact, it is a dual projection corresponding to each of the Celestial Hemispheres, one of which had its viewpoint at the beginning of Aries and the other at the beginning of Libra. The end result was obtained by superimposing the projection from Aries (turning it) onto the projection from Libra. The two variants of the *ṣafīḥa* differ slightly. The *zarqāliyya* has, on its face, a double grid of equatorial and ecliptical coordinates and a ruler horizon representing the horizontal ones. On its back, in addition to the features proper to the astrolabe, it shows an orthographic meridian projection of the sphere, a trigonometric quadrant, and a small circle (named "of the Moon") used to compute the geocentric distance of the Moon. The *shakkāziyya* is a simplification of the *zarqāliyya*, as Marrākushī states in his *Jāmiʿ*. On its front it bears a single grid of equatorial coordinates and a grid of ecliptical ones reduced to the ecliptic line and the circles of longitude marking the beginning of the zodiacal signs. The back of this kind of *ṣafīḥa* is the same as the back of the astrolabe. There is an Alfonsine translation of the treatise on the *zarqāliyya*, as well as several translations into Latin and Hebrew of the treatise on the *shakkāziyya*.

Roser Puig

Alternate name

Azarquiel

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Zeeman, Pieter

Born **Zonnemaire, the Netherlands, 25 May 1865**
Died **Amsterdam, the Netherlands, 9 October 1943**

Dutch physicist Pieter Zeeman made the laboratory discovery of the effect bearing his name, in which spectral lines emitted or absorbed by atoms in magnetic fields are slightly shifted in wavelength and polarized. He shared the 1902 Nobel Prize in Physics with **Hendrik Lorentz** who had immediately provided a theoretical explanation of the observation for "their researches into the influence of magnetism upon radiation phenomena."

Zeeman was educated at the University of Leiden in the laboratory directed by Keike Kamerlingh Onnes (Nobel Prize 1913 for his discovery of liquid helium), receiving his Ph.D. in 1893. He remained for several years as a *Privatdozent* and lecturer, before being appointed to a professorship at the University of Amsterdam and, in 1908, also as director of the Physical Institute there.

The critical experiments were done in Leiden in 1896, apparently over some considerable objection by Onnes. Zeeman had the good fortune to select neutral sodium gas for his investigation. It has a single active electron when in its ground state and so displayed what is now called a normal Zeeman pattern, splitting into two or three components in a magnetic field (with the amount of the split proportional to the strength of the field). When one looks along the direction of the field, one sees two components shifted in opposite directions, with oppositely directed circular polarization (the longitudinal components). Perpendicular to the field, one sees three components: two shifted components with linear polarization perpendicular to the field, and one undeviated, with polarization along the field direction. Lorentz was able to explain these results (and also the relative intensities and angular beaming of the components) in terms of radiation by individual electrons, discovered in 1897 by J. J. Thomson. Sodium was a lucky choice, because other elements, with several active electrons, can display a dozen or more shifted "anomalous" Zeeman components, which require the quantum mechanics of the 1920s for their explanation.

Zeeman's importance for astronomy lies in the application of his effect to the measurement of magnetic fields in the Sun, stars, and interstellar medium. In 1908, he guided **George Hale** in the interpretation of lines in the spectra of sunspots when they were observed near the center of the solar disk. The observed splitting into two components implied a magnetic field directed radially in the spot umbrae. Thus, Zeeman concluded, spots on the solar limb should show three components with appropriate polarizations. This turned out to be the case, with the field in sunspots ranging up to about 6,000 G in strength. Later, **Horace Babcock** searched for Zeeman broadening and polarization of spectral features produced in the atmospheres of other stars, finding strengths up to more than 30,000 G for some A-type stars. The strongest fields recognized from the Zeeman effect, nearly 1 billion gauss, are found in white dwarfs, and have been measured by **Jesse Greenstein** and others. Much weaker fields (of a thousandth of a gauss) in interstellar gas clouds also have been revealed by the Zeeman polarization of atomic and molecular features at radio wavelengths.

Zeeman's later work was in the general area of the propagation of electromagnetic radiation through various media in the presence of electric and magnetic fields. This included the topic of his Ph.D. dissertation, the Kerr effect, in which a liquid (whose molecules have been partially aligned by an applied electric field) transmits light of perpendicular polarizations at slightly different speeds. The polarizations get out of phase, and, with proper choice of parameters, light can pass through the Kerr cell only when the field is turned on.

Anne J. Kox

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Zeipel, Edvard Hugo von

Born **Uppsala, Sweden, 8 February 1873**
Died **Uppsala, Sweden, 8 June 1959**

Swedish mathematical astronomer Edvard von Zeipel is renowned for von Zeipel's theorem and von Zeipel's paradox, closely related topics in the theory of rotating stars.

After finishing studies at Uppsala University in 1904, von Zeipel moved to Paris to increase his knowledge of celestial mechanics under the supervision of **Henri Poincaré**; subsequently he visited the Pulkovo Observatory for a long time. In 1904, he was appointed associate professor of astronomy at Uppsala University, and full professor in 1920. After 1911 he also held the position of the observer (*Observator Regius*) at Uppsala Observatory, until retirement in

1938. Von Zeipel was one of the founding personalities of the Swedish Astronomical Society and president during the years 1926 to 1935. In honor of him, minor planet (8870) bears his name.

The scientific interests of von Zeipel were concentrated on several topics, mainly theoretical in nature. In celestial mechanics, he developed a Hamiltonian formalism of short-term, long-term, and secular perturbations and applied it on the changes of orbits of periodic comets and minor planets including those with orbital elements like that of (108) Hecuba. The method followed an idea of Poincaré and is often referred to as the von Zeipel method.

In 1924, von Zeipel proved (in a literal, mathematical sense) that a star in rigid rotation (like the Earth) must have a very particular distribution of sources of energy such that the energy release would be negative in the outer parts. This was clearly not true. The problem was recognized a year later by **Arthur Eddington** and **Heinrich Vogt** and is sometimes called von Zeipel's paradox. The solution is that, if the distribution of energy release is not the required one, then it sets up currents that are primarily in planes through the axis of rotation (meridional circulation), which are important in gradually mixing stellar material.

Von Zeipel's theorem, also from 1924 and derived by **Edward Milne** as well, states that the local surface brightness of a point on a star is proportional to the local acceleration due to gravity, including the effects of rotation, tidal distortion by another star or planet, and so forth. This is still a useful guide in interpreting observations of stellar atmospheres.

The last topics of von Zeipel's work were the problems of stellar masses and distributions of stars within globular clusters.

Martin Solc

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Zel'dovich, Yakov Borisovich

Born **Minsk, (Belarus), 8 March 1914**
Died **Moscow, (Russia), 2 December 1987**

Soviet theoretical physicist Yakov Zel'dovich made his mark in the astronomical world as founder of the Soviet school of astrophysics and cosmology, within which many ideas of current importance were formulated at the same time (between about 1955 and 1975) as they were being developed in the United States and Europe. Zel'dovich was born into a Jewish family of too high a social class to be initially eligible for college training in Stalin's USSR, and he began his career as a laboratory technician. Zel'dovich's great promise was recognized by more senior scientists, and he was then educated at the Institute of Physics and Technology in Leningrad and the Institute of Chemical Physics, obtaining the degree of Candidate of Sciences in 1936. He was later professor at Moscow State University and divisional head at the Sternberg Astronomical Institute.

Work on the Soviet nuclear program meant that Zel'dovich was 68 when he first traveled outside the Soviet sphere. Nevertheless, his international influence, particularly in cosmology, has been immense. He published around 500 papers, founded a whole school of scientific thought in the Soviet Union, and had close to 100 scientists who would consider themselves to have been his student.

Zel'dovich married several times. All six of his children and several of his grandchildren eventually earned Ph.D.s, largely in the physical sciences. His son Boris Yakovich Zel'dovich is a distinguished condensed-matter physicist.

Yakov Zel'dovich's early work was in chemical physics, including the theory of combustion and detonation, and contributed to the understanding of solid-fuel burning; there is a Zel'dovich number in the theory of combustion. He was also among the first to understand the importance of chain reactions in uranium, and became a leader in the Soviet nuclear program. By the late 1950s he had begun working on elementary particle physics. This led to early limits on particle properties using cosmological considerations.

From the early 1960s Zel'dovich was leading the Soviet efforts in relativistic astrophysics and cosmology. He worked on accretion onto black holes, suggesting in 1964 (simultaneously with Edwin Salpeter) that supermassive black holes could be the energy source of quasars.

With several younger colleagues, Zel'dovich wrote about the possibility of discovering neutron stars and black holes if they happened to be in binary systems, because the transfer of material from a normal star onto a compact one would result in the emission of X-rays. The key papers were published shortly before an improved position for the first extra-solar-system X-ray source, Sco X-1, permitted an optical identification and led a number of other theorists to similar considerations.

Zel'dovich was one of the first to point out the importance of using the Cosmic Microwave Background [CMB] to probe the early history of density perturbations. With Andrei Doroshkevich, Rashid Sunyaev, and others, he worked out the physics of the era of hydrogen recombination and early estimates of the microwave anisotropies. Zel'dovich also studied primordial nucleosynthesis and early Universe particle physics, including the behavior of neutrinos, quarks, and monopoles. He calculated how the CMB spectrum would be distorted by unstable particles, evaporation of mini black holes, annihilation of antimatter, *etc*. On top of this he investigated the origin of astronomical magnetic fields and dynamo theory, among other diverse topics.

Later Zel'dovich worked on the birth and spontaneous creation of the Universe, having some ideas that were forerunners of inflation, which he embraced in the 1980s. Zel'dovich also proposed (independently of Edward Harrison and James Peebles) a spectrum of initial perturbations that has equal power at all scales at horizon crossing. This popular assumption is often referred to as the Harrison–Zel'dovich spectrum.

Zel'dovich's work on the subsequent growth of such cosmological perturbations led to the Zel'dovich pancake picture, which he espoused in the 1970s. He invented a clever trick of using linear particle displacements to study nonlinear density enhancements up to the formation of these pancakes, a method which is termed the el'dovich approximation.

Zel'dovich's name is probably most commonly mentioned now in reference to the Sunyaev–Zel'dovich effect, which is the inverse

Compton scattering of CMB photons off hot electrons in clusters of galaxies. This effect, first described in the early 1970s, has become an important tool for understanding the physical properties of clusters, as well as for determining fundamental cosmological parameters.

Zel'dovich was elected a foreign member of the United States National Academy of Sciences [NAS] and of the Royal Society (London) as well as to membership in the Soviet Academy of Sciences. He received a number of prizes and medals from both Soviet and foreign organizations.

Zel'dovich was able to travel to the United States only once (to address the NAS) and died after suffering an unexpected heart attack, under circumstances that would probably not have been fatal in other countries. He was a widely read polymath even outside the sciences, quite unable to understand how scholars in the United States and Europe, with the right to read absolutely anything they wanted, could take so little advantage of their opportunities.

Douglas Scott

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Zhamaluding: Jamāl al-Dīn Muḥammad ibn Ṭāhir ibn Muḥammad al-Zaydī al-Bukhārī

Flourished **(Mongolia) and Beijing, China, *circa* 1255–1291**

The Muslim astronomer Zhamaluding (Chinese transliteration of Jamāl al-Dīn) was the first director of the Islamic Astronomical Bureau established in Beijing in 1271. He was involved in the compilation of a *zīj* (astronomical handbook with tables) in Persian, which was largely based upon newly observed planetary parameters and was translated into Chinese, under the title *Huihuilifa*, during the early Ming dynasty. Furthermore, Zhamaluding's name is associated with a "Geography of the Yuan empire," finished in 1291.

Most of the historical information concerning Zhamaluding stems from the official annals of the Yuan dynasty, the *Yuanshi*, and from the "Annals of the Yuan Office of Confidential Records and Books" (*Yuan bishujian zhi*, reprinted in the *Sikuquanshu*). It appears that Zhamaluding was in the service of the Mongol Great Khans from the 1250s onward. A certain Jamāl al-Dīn Muḥammad ibn Ṭāhir ibn Muḥammad al-Zaydī al-Bukhārī, hailing from the region of Bukhara in present-day Uzbekistan and presumably identical with Zhamaluding, is mentioned in the *Jāmiʿ al-tawārīkh* (World history) of the famous Persian historian Rashīd al-Dīn (died: 1317) as not having been capable of carrying out the construction of an astronomical observatory for Möngke Khan (1251–1259) in his capital Karakorum in central Mongolia. Möngke's successor Khubilai had already consulted Zhamaluding and other Muslim astronomers before he became the first emperor of the Yuan dynasty in 1264 and moved his capital to Beijing (Dadu). Three years later, Zhamaluding presented to Khubilai the *Wannianli* (Ten thousand-years calendar, presumably an Islamic *zīj*), which was for a short period distributed as an official calendar but is no longer extant. Furthermore, Zhamaluding offered models or depictions of seven astronomical instruments of Islamic type, namely an armillary sphere, a parallactic ruler, an instrument for determining the time of the equinoxes, a mural quadrant, a celestial and a terrestrial globe, and an astrolabe.

In 1271, Khubilai Khan founded an Islamic Astronomical Bureau with observatory, which was to operate parallel to the traditional Chinese bureau. He thus maintained the bureaucratic structure of the preceding Jin dynasty, but at the same time allowed Chinese observations and predictions to be checked against those of the highly respected Muslim astronomers. Zhamaluding became the first director of the Islamic Bureau and headed a staff of approximately 40 persons, including astronomers, teachers, and administrative personnel. Because, in particular during the 1260s, tens of thousands of Muslims had arrived in China, it need not surprise us that the staff included capable astronomers and that a large observational program could be carried out in order to redetermine most of the planetary parameters and to measure anew the longitudes and latitudes of hundreds of fixed stars. The Islamic Astronomical Bureau of Yuan China thus became one of the very few Islamic institutions where observations were carried out at such a large scale. Although the bureau was not abolished until 1656, its direct influence on Chinese astronomy was very limited and no Islamic methods were incorporated into the official calendar of the Yuan dynasty, the *Shoushili*, by **Guo Shoujing**.

Zhamaluding was also one of the directors of the imperial "Office for Confidential Records and Books" (*bishujian*), to which both astronomical bureaus were subordinate. The extant annals of this office contain a list of books and instruments present at the Islamic Observatory and in Zhamaluding's private library. From the Chinese transliterations of the book titles and brief descriptions, it can be seen that the following works were available: the *Almagest* of **Ptolemy**, the *Elements* of Euclid, the *Madkhal* (Introduction to astrology) by **Kūshyār ibn Labbān**, the *Stellar constellations* by **Ṣūfī**, *zīj*es, and books on *hay'a* (cosmology) and the construction of instruments. The transliterations were clearly made from the Persian (rather than from the Arabic), as can be seen from certain grammatical elements and some small variations in terminology.

Zhamaluding was very probably the author of a *zīj* in Persian, or at least was associated with its compilation. The original of this work is lost, but a Chinese translation entitled *Huihuilifa* (Islamic calendar) has drawn the attention of Chinese scholars ever since its publication in the annals of the Ming dynasty (*Mingshi*) prepared in the late 17th century. The translation was made in 1383 by a Muslim astronomer, Ma-shayihei (possibly a *shaykh* who had assumed the common Chinese surname for Muslims, Ma), in cooperation with Chinese scholars. This project, which also included a translation of Kūshyār's *Madkhal*, was carried out at the Astronomical Bureau of the new capital Nanjing on the order of the first emperor of the Ming dynasty, Hong Wu.

In recent years the number of known sources from which the contents of Zhamaluding's original *zīj* may be reconstructed has significantly increased. A late-15th-century restoration of the Chinese translation by the vice director of the Astronomical Bureau in Nanjing, Bei Lin, as well as a Korean reworking made on the order of King Sejong (1419–1451), turned out to be more complete than the version published in the *Mingshi*. An Arabic *zīj* written in Tibet in 1366 by al-Sanjufīnī contains many tables taken directly from the *Huihuilifa* and others that were derived from that work. Al-Sanjufīnī's solar tables are said to be based on the "Jamālī observations," *i. e.*, probably, those carried out under Zhamaluding. A Persian–Arabic manuscript at the Oriental Institute in Saint Petersburg, Russia, which was clearly copied by someone who did not know Arabic or Persian very well, was presumably a working document of the Chinese translators, since it contains original tables for Beijing besides newly computed ones for Nanjing.

An investigation of all these sources has shown that Zhamaluding's original *zīj* contained planetary tables of standard Ptolemaic type, but based on mostly new values for the mean motions, eccentricities, and epicycle radii. For example, the solar mean motion in longitude as found in the *Huihuilifa* implies a length of the tropical year (in sexagesimal notation) of 365;14,31,55 days, one of the most accurate values hitherto found in Islamic sources (the actual year length in 1300 was approximately 365.242236, *i. e.*, 365;14,32,3 days). Zhamaluding's method for predicting solar and lunar eclipses appears to be a mixture of Islamic and Chinese methods. The origin of the star table in the *Huihuilifa*, which lists non-Ptolemaic longitudes, latitudes, and magnitudes of 277 stars near the ecliptic with Ptolemaic as well as Chinese star names, has not yet been completely clarified. The translators in the early Ming dynasty certainly made various modifications to this table, which they utilized for the calculation of so called encroachments (*lingfan*), *i. e.*, passings of the Moon and planets through stellar constellations, which were highly significant in Chinese astrology.

In 1286, undoubtedly as a senior scholar, Zhamaluding suggested to Khubilai a large-scale geographical survey of the Yuan empire. He became the head of an office especially established for this purpose and, since he did not speak Chinese, was provided with a personal translator. The result of the survey, the *Dayitongzhi* (Geography of the whole empire) in 755 volumes, was offered to the emperor in 1291 and finally printed in 1347. Unfortunately, only the introduction of this work is extant.

Benno van Dalen

Alternate name

Jamāl al-Dīn

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Zhang Heng

Born **Xi'e, (Henan), China, 78**
Died **Luoyang, (Henan), China, 139**

Zhang Heng (public name, Pingzi) was a Chinese astronomer and man of letters in the later (eastern) Han dynasty who first fully described the *huntian* or spherical-Earth cosmological model.

In his youth, Zhang Heng traveled to Chang'an (capital of the former Han dynasty) and Luoyang (capital of the later Han dynasty), and studied several subjects. He was appointed an imperial official by Emperor An (reigned: 106–125) and promoted to the post of *Taishiling* (director of the Bureau of Astronomy and Calendrics) shortly thereafter. He was reappointed *Taishiling* by Emperor Shun (reigned: 126–144).

The Chunqiu and Zhanguo ("Spring and Autumn" and "Warring States") periods (770–221 BCE) can be said to be the period of preparation of classical Chinese astronomy. In this era, the 28 lunar mansions were first established and the divisions of the tropical year (which finally became the 24 *qi*-nodes during or just before the early former Han dynasty) came into use. The naive cosmology in this period was the *tianyuan difang* theory, which described a circular heaven over a square Earth. This model developed into the *gaitian* theory of the former Han dynasty, according to which the upper heaven resembled the canopy of a carriage and the lower Earth an inverted bowl.

The former (western) Han dynasty (206 BCE–8) can be said to be the period of establishment of classical Chinese astronomy. The Taichu calendar, which established the standard style of the classical Chinese calendar, was devised in 104 BCE. Luoxia Hong, who was one of the major contributors to the establishment of the Taichu calendar, is said to have invented the *huntianyi* (or *hunyi*) or armillary sphere. At this time, only right ascension must have been measured to which north polar distances were added slightly later. The Taichu calendar of 104 BCE was developed into the Santong calendar of Liu Xin (died: 23) at the end of the former Han dynasty.

The invention of the armillary sphere must be connected with the development of the *huntian* theory of cosmology, in which heaven is considered to be spherical and the Earth is at its center. This theory was fully developed by Zhang Heng of the later Han dynasty, and subsequently became the orthodox theory in classical Chinese astronomy.

Classical Chinese astronomy continued to develop during the later (eastern) Han dynasty (25–220). A new later Han Sifen calendar was made in the year 85.

Also the armillary sphere continued to develop. Previously, during the former Han dynasty, the armillary sphere was only used to measure equatorial coordinates, and at that time, Gen Shouchang noticed that the movement in right ascension of the Sun and the Moon was not uniform. This inequality corresponds to the reduction to the Equator. At the beginning of the later Han dynasty, a nongovernment astronomer, **Fu An**, began to observe the movement of the Sun and Moon along the ecliptic, probably for the first time in China. Then, Li Fan and Su Tong discovered that the movement of the Moon is not uniform even if it is measured along the ecliptic. **Jia Kui** analyzed their discovery, and concluded in his report (92) that this is due to the real inequality of lunar motion caused by the varying distance of the Moon, and that the point on the lunar orbit where the Moon's speed is fastest revolves once in 9 years. This inequality evidently corresponds to the equation of the center of the Moon.

An instrument with an ecliptic circle was originally used by nongovernment astronomers. The first official instrument with an ecliptic circle is said to have been made in 103. Zhang Heng also made an armillary sphere and a celestial globe, as discussed later. The obliquity of the lunar orbit to the ecliptic was also discovered in the later Han dynasty. This fact and the inequality of lunar motion were taken into consideration in the Qianxiang calendar composed by Liu Hong in 206.

During the Han dynasty, there were three theories of cosmology, namely, the *gaitian* theory (where the hemispherical dome of heaven and Earth's surface are parallel), the *huntian* theory (where heaven is spherical), and the *xuanye* theory (where heaven is infinite). Of the three, the *huntian* theory became the orthodox theory. Zhang Heng fully developed the *huntian* theory, and composed the cosmological works, the *Lingxian* (Sublime constitution of the Universe) and the *Hunyi* (Commentary on the armillary sphere). The latter is sometimes called *Hunyizhu*.

In his *Hunyi,* Zhang Heng wrote that heaven is like the shell of a hen's egg, and the Earth is at its center like the yolk of an egg. Probably, the Earth was considered to be flat. As heaven was thought to be spherical, spherical coordinates could be set up. Chinese equatorial coordinates consisted of right ascension, for which the hour circles passing through the determinative stars of the 28 lunar mansions were used as datum lines, and the north polar distance. The angular distance was measured in terms of *du*, which is the angular distance on the celestial sphere through which the Sun moves in one day. (It may be noted here that the term *du* is now used to denote "degree" in modern Chinese.)

Some Chinese astronomers also used the polar longitude, that is, the longitude of the hour circle passing through the object on the ecliptic, for which datum lines are also the hour circles passing through the representative stars of the 28 lunar mansions. The conversion of polar longitude and right ascension was performed graphically on the celestial globe. In his *Hunyi*, Zhang Heng recorded a method to convert the right ascension of the Sun into longitude on the celestial globe.

According to his *Hunyi*, Zhang Heng constructed an armillary sphere called the *tongyi* (bronze instrument) for observational purposes, and a celestial globe called *xiaohun* (small sphere) for demonstration and graphical calculation. According to a later historical record (*Jin shu*), Zhang Heng's celestial globe was rotated by waterpower in a room, and its movements coincided precisely with the actual movement of the sky. Details of its construction are not recorded, but it was evidently the first water-driven celestial globe in China.

The water clock is said to have been used in the Chunqiu and Zhanguo periods (770–221 BCE), but how it was constructed is not recorded. Extant water clocks date back as far as the former Han dynasty and are simple outflow type. According to his fragmentary work *Loushuizhuan huntianyi zhi* (Construction of the water-driven armillary sphere), Zhang Heng built an inflow-type water clock with double reservoir. The double reservoir was intended to make the water flow constant. As water is supplied by the upper reservoir, the water level and water flow of the lower reservoir do not decrease much. This was the first attempt to make the water flow constant in China. Due to the different lengths of daytime and nighttime hours, different acceptors were used for day and night. The technique of making the water flow of the water clock constant was further developed later in China.

Zhang Heng's astronomical works, the *Lingxian*, the *Hunyi*, and the *Loushuizhuan huntianyi zhi*, exist as fragmentary quotations in later works, and are collected in compilations of such fragments, for example the *Quan Hou Han wen* (Complete collection of writings of the later Han dynasty), chapter 55 in the *Quan Shanggu sandai Qin Han Sanguo Liuchao Wen* (Complete collection of writings from high antiquity, the Three Dynasties, Qin, Han, Three Kingdoms, and Six Dynasties) of Yan Kejun (1762–1843), and the "*Tianwen lei*" (Works of astronomy) in the *Yuhanshanfang jiyi shu* of Ma Guohan (1794–1857).

Alternate name

Chang Heng

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Zhang Sixun

Born **(Sichuan), China, 10th century**

Zhang Sixun was renowned as the maker of an important armillary. After successfully passing the astronomical examination at the Northern Song court in 978, Zhang Sixun was assigned the work of designing and making astronomical instruments at the Imperial Bureau of Astronomy and Calendrics in the capital Kaifeng. Because he had studied astronomical instruments before the examination, it was not long after his assignment that he designed and made an astronomical instrument (979). The instrument was named Taiping hunyi (Armillary sphere of the great peace) by Emperor Taizong. At the time Zhang Sixun was serving as a junior official in charge of administering astronomical instruments.

The Taiping Hunyi had the shape of a three-story building. The lower and middle stories contained devices to announce the hours, and in the upper one there was a celestial globe. The height of the instrument was about 4 m. The power for the machines in the instrument was supplied by flowing mercury. All the machines and devices were installed inside the building and could not be seen from the outside. At each quarter hour, three wooden puppets would come out of the lower building to announce the time by producing sounds. The puppet on the left shook small bells, the middle one beat a drum, and the one on the right rang a bell, after which they reentered the building. In the middle story, there were 12 images of deities with different appearances that would alternately move in and out on the hour to show the time.

On the celestial globe in the upper story, the Sun, Moon, and five planets (Venus, Jupiter, Mercury, Mars, and Saturn) were depicted. It is recorded that they could move along the surface of the globe, but we do not know how this was accomplished. The surface of the globe further showed the Chinese constellations, the Celestial Ecliptic, and the Celestial Equator. The globe rotated once a day. It is said that people could look up and watch it, but where they stood, is not mentioned.

Obviously, the Taiping Hunyi was a large astronomical instrument. It was highly praised in its time. The design is thought to have come from Zhang Sui's (also **Yixing**) Shuiyun hunyi (Water-driven armillary sphere). The Taiping hunyi was also the forerunner of the famous Shuiyun yixiang tai (Tower of the water-driven celestial globe) designed by **Su Song**.

Li Di

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Zinner, Ernst

Born **Goldberg (Slask, Poland), 2 February 1886**
Died **Planeg near Munich, (Germany), 20 August 1970**

German astronomer–historian Ernst Zinner is known primarily for the compilation of very extensive bibliographies of manuscripts and books about astronomy written from the late Middle Ages to the 18th century, and for his own monographs on the history of astronomy.

Zinner attended the Gymnasium in Legnica (over Breslau [Wroclaw]) and studied astronomy and mathematics in Jena and Munich, receiving his doctorate from Jena for work under O. Knopf on a classic problem in astrometry – the reduction of observed to real places of stars. Zinner continued study of astronomy at Lund, Sweden, with **Carl Charlier**, at Paris with **Jules Poincaré**, and at Heidelberg; moving to Bamberg in 1910, where he carried out a major project on historical light curves of variable stars and codiscovered short-period comet 21P/1913 U1 (Giacobini–Zinner). During World War I, Zinner served in the field weather service, followed by a term with the Bavarian Commission for the International Measurement of the Earth (analyzing gravity measurements made in Bavaria), and appointment as professor at Munich in 1924.

In 1926, Zinner was named director of the Bamberg Observatory, retaining the position until his retirement in 1953. His first project there included extensive tables of the apparent brightnesses of stars and of variable star light curves, the latter drawing on observations by **Friedrich Winnecke**, **Arno Wachmann**, and **Ernst Hartwig**. But Zinner's interests were turning ever more strongly to the history of astronomy, particularly the identification and indexing of manuscript sources and books published in German. He visited, as much as possible, the actual facilities holding such works throughout Europe. His published works include a 1925 index of manuscripts, a 1941 history and bibliography of German Renaissance astronomical literature, and a 1936 catalog of German and Dutch astronomical instruments built between the 11th and 18th centuries (and the instrument manufacturers who produced them). The library and museum collections Zinner recorded underwent considerable changes during and after World War II, and historians have not yet quite caught up in producing modern catalogs and bibliographies as extensive as his.

The most notable of Zinner's own historical monographs was the 1931 *History of Astronomy*. It stands out for its extensive discussion of the astronomy of the Jews, Persians, Indians, Chinese, and other East Asian peoples, as well as the preliterature astronomy of the Celts and early Slavs. Curiously, everything lying outside Greek, Roman, and Arabic astronomy appeared under the heading "astronomy of the Germans." This included the work of **Galileo Galilei**, **Isaac Newton**, and even American astronomers. Part of this was conformity to the dominant political views of German cultural and scientific preeminence at the times and places when and where Zinner was writing.

Zinner's studies of **Johann Müller** (Regiomontanus) led him to publish in 1937 a facsimile of the earlier scholar's calendar, which originally appeared in 1474, and, in the following year, to complete his greatest monograph, in which he fully appreciates the value of this influential 15th-century astronomy. Zinner's *Entstehung und Ausbreitung der coppernicanischen Lehre* (Origins and dissemination of Copernican teaching) appeared in 1943, and it is a work still worthy of the fullest consideration by every historian.

A significant portion of Zinner's scientific collection, including 2,700 books and editions of journals, manuscripts, autographs, portraits of scholars, and scientific images, was purchased by the San Diego State University and is kept as the Ernest Zinner collection. Another portion of his collection was donated to the Institute for the History of Physics in Frankfurt am Main.

Jürgen Hamel

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Zöllner, Johann Karl Friedrich

Born **Berlin, (Germany), 8 November 1834**
Died **Leipzig, Germany, 25 April 1882**

From an early age, Johann Zöllner displayed strong mechanical aptitude and fabricated various scientific instruments. Although Zöllner's father wished him to take over the management of his factory, the youth wanted no part of the business. In 1855, he began to study physics at the University of Berlin. Two years later, he enrolled at the University of Basel. By 1859, Zöllner had earned a Ph.D. for research on photometric problems. This work was later published as *Photometrische Untersuchungen* (1865).

Under Zöllner's direction, an instrument named the astrophotometer was constructed at Aarau. This device enabled a direct comparison to be made between an artificial star and a star observed through a telescope. Zöllner's methodology formed the basis of later research at the Potsdam Observatory and its *Photometrische Durchmusterung*.

Zöllner was appointed as professor of physical astronomy at the University of Leipzig in 1866. Another of his inventions, the reversion spectroscope, enabled the dispersion of spectral lines to be effectively doubled. This technique proved valuable in the measurements of Doppler shifts associated with the rotational velocities of sources. Zöllner undertook studies of the Sun's temperature and constitution, and of the nature of comets. He proposed a theory that comets vaporize while in close proximity to the Sun, described in his *Uber die Natur der Cometen* (1872). He also fabricated the horizontal pendulum, later used extensively in geophysical research.

Zöllner was elected to the Saxon Academy of Sciences at Leipzig and as an associate member of the Royal Astronomical Society in 1872. His later life was increasingly devoted to aspects of spiritualism, while his scientific productivity (and reputation) correspondingly declined.

Fathi Habash

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Zu Chongzhi

Born **Fanyang, (Hebei), China, 429**
Died **500**

Zu Chongzhi (public name, Wenyuan) was a Chinese mathematician and astronomer of the Southern dynasties during the Northern and Southern dynasties period (420–589).

Zu Chongzhi served as an official during the Song (Liu-Song) dynasty (420–479) and southern Qí dynasty (479–502). He made a new calendar entitled the Daming calendar, and requested to use it officially in 462. He was strenuously opposed, and the calendar was not accepted. Zu Chongzhi's son Zu Gengzhi (or Zu Geng) was also a mathematician and astronomer. Thanks to Zu Gengzhi's efforts, the Daming calendar was officially used, beginning in 510.

It was during the eastern Jìn dynasty (317–420) that the precession of the equinoxes was discovered by Yu Xi (281–356; probably independently of **Hipparchus**). After the fall of eastern Jin in 420, the northern and southern dynasties period (420–589) began. In the Song (Liu-Song) dynasty (420–479), the first of the southern dynasties, an astronomer named He Chengtian (370–447) made an excellent calendar called the Yuanjia calendar. Before this, all Chinese calendars assumed that the length of a calendrical synodic month to be constant, although the inequality corresponding to the equation of the center of the Moon had been discovered in the 1st century during the later Han dynasty. He Chengtian tried to adjust the first day of a calendrical synodic month to the true conjunction of the Moon, corrected by the lunar inequality, and proposed a new calendar in 443. However, he was opposed by **Qian Lezhi**, the then director of the Imperial Bureau of Astronomy and Calendrics, and Yan Can, the deputy director. They felt that the new calendar was too complicated, although **Qian Lezhi** and others admitted that He Chengtian's calendar was quite accurate. He Chengtian modified his calendar and made the length of a calendrical synodic month constant. In 445, He Chengtian's Yuanjia calendar was finally accepted as an official calendar. This controversy shows how opinions could diverge regarding the difference between mathematical astronomy as a pure science and the civil calendar as applied technology.

Zu Chongzhi thought that He Chengtian had carried out a reform, but his calendar was still inaccurate. Zu Chongzhi then devised a more accurate calendar called the Daming calendar. However, he was strenuously opposed by the conservative Dai Faxing. (Mention may also be made here of **Zhang Sixun** of the northern dynasties, who discovered the inequality corresponding to the equation of the center of the Sun in the 6th century, probably independently of ancient Mediterranean astronomy.) Most Chinese calendars before Zu Chongzhi used the 19-year cycle for intercalation, during which 7 intercalary months are added. This cycle is called the *zhang*, and was already in use by the end of the "Warring States" period (475–221 BCE). Although this cycle is the same as the Greek Metonic cycle, the Chinese and Greek cycles are probably independent discoveries. The earliest Chinese calendar to abandon the 19-year cycle was the Xuanshi calendar (412) of Zhao Fei of the northern Liang dynasty (396–440), who used a 600-year cycle during which 221 intercalary months were added. The Daming calendar (462) of Zu Chongzhi was the second to abandon the 19-year cycle; it used a 391-year cycle during which 144 intercalary months were added.

Another important innovation of the Daming calendar of Zu Chongzhi is that it took into account the precession of the equinoxes. Precession had already been discovered by Yu Xi (281–356), but Zu Chongzhi was the first to accept it in a calendar. The Daming calendar also used a length of the nodical month 717,777/26,377 (= 27.212230…) days, which is quite accurate.

Zu Chongzhi further devised a method to determine the exact time of the winter solstice from observations of the midday gnomon shadow.

Zu Chongzhi also was a great mathematician. He calculated that the value of π lies between 3.1415926 and 3.1415927. He is said to have composed a high-quality mathematical work *Zhuishu*, which is not extant.

Alternate name

Tsu Ch'ung-chih

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Zucchi, Nicollo

Born **Parma, (Italy), 1596**
Died **Rome, (Italy), 1670**

Nicollo Zucchi taught mathematics at the Jesuit Roman College, did impressive research in optics, and was a well-known telescope maker. **Joseph de Lalande** speaks with great admiration of his contributions to the reflecting telescope. He designed an apparatus using a lens to observe the image focused by a concave mirror, thus providing an early version of the reflecting telescope. From his description of this apparatus in his *Optica*, other scientists such as **Isaac Newton** were able to make necessary improvements on this instrument. Using his reflecting telescope, Zucchi made a careful study of the spots on Mars (which had already been discovered), and from this data **Jacques Cassini** was able to discover the rotation rate of Mars.

Zucchi was held in such great esteem that he was sent as a papal legate to the court of Emperor Ferdinand II of Austria, where he met **Johannes Kepler**. One of the most touching of Kepler's letters was the dedication of his last book, *The Dream* (1634), which contains a long letter of gratitude to Jesuits **Paul Guldin** and Zucchi, who brought Kepler a telescope during his exile:

> To the very reverend Father Paul Guldin, priest of the Society of Jesus, venerable and learned man, beloved patron. There is hardly anyone at this time with whom I would rather discuss matters of astronomy than with you. Father Zucchi could not have entrusted this most remarkable gift – I speak of the telescope – to anyone whose effort in this connection pleases me more than yours.

A lunar crater is named to honor Zucchi: It is 64 km in diameter and is located at 61°.4 south latitude and 309°.7 east longitude.

Joseph F. MacDonnell

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Zupi, Giovan Battista

Born **Catanzaro, (Calabria, Italy), 2 November 1589**
Died **Naples, (Italy), 26 August 1667**

Giovan Zupi was one of the earliest telescopic observers of Jupiter's bands. In the year 1610 Zupi became a Jesuit priest. After teaching humanities, philosophy, and theology, he was teacher of mathematics in the Jesuit College in Naples for 27 years.

Zupi was very active as an observer in collaboration with **Francesco Fontana**, who employed a telescope made of two convex lenses. Fontana, in his book *Novae Coelestium*, attributes to Zupi the early observation of what would become known as Jupiter's belts and zones. **Giovanni Riccioli** mentions in his *Almagestum Novum* Zupi's observations of Jupiter's bands and also many other observations of the planet Mercury. Riccioli included Zupi's name in his lunar map. There are no known books written by Zupi.

Juan Casanovas

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Zwicky, Fritz

Born **Varna, Bulgaria, 14 February 1898**
Died **Pasadena, California, USA, 8 February 1974**

Swiss–American physicist and astrophysicist Fritz Zwicky is remembered as more or less the first:

(1) to point out the very large amounts of dark matter in rich clusters of galaxies;

(2) to show that gravitational lensing of one galaxy by another is much more likely than star–star lensing; and
(3) with **Walter Baade** to associate the supernova phenomenon with the formation of neutron stars and the acceleration of cosmic rays.

Zwicky was born into a family of Swiss merchants working abroad, and returned with them to the village of Mollis, in the home canton of Glarus (where he was eventually buried) in 1904. Though employed for nearly his entire career in the United States, he remained a Swiss citizen, returning home to vote, and remarking that "a naturalized citizen is always a second-class citizen." Zwicky was educated at the Eidgenossische Technische Hochschule [ETH] (Swiss Federal Institute of Technology), completing a diploma thesis (first degree) under mathematician **Herman Weyl** and a Ph.D. dissertation in theory of crystals under Peter Debye (winner of the 1936 Nobel Prize in Chemistry) and Paul Scherrer in 1922. Following a 3-year period as an assistant at the ETH, Zwicky moved in 1925 to the California Institute of Technology (Caltech), at the invitation of its president **Robert Millikan**, receiving a Rockefeller Fellowship from the International Education Board to support 2 years' work there.

Zwicky remained at Caltech the rest of his professional career as assistant (1927–1929), associate professor of physics (1929–1942), and professor of astrophysics (1942–1968), the first person to hold such a title there. Millikan had expected Zwicky to work on quantum theory of solids and liquids, and he indeed published in these areas, but his primary interests gradually turned to astrophysics, beginning with cosmic rays and ideas for how they might arise. In 1929, very shortly after the announcement of the expansion of the Universe by **Edwin Hubble**, Zwicky suggested that the data (a linear correlation between distance and redshift) might equally well be explained by "tired light," that is, the idea that photons simply become less energetic after traveling very long distances. This alternative was finally ruled out only about 60 years later, with the discovery of supernovae in distant galaxies and their time-dilated light curves, showing that the expansion is real. Zwicky himself remained suspicious of large redshifts, and carefully referred to "symbolic velocities," although much of his work in fact assumed the standard redshift–distance relation.

In 1933, Zwicky measured redshifts for galaxies in the Coma cluster, and found that they were not all quite the same. Instead, there was a spread in velocities of the cluster members, which required a very large mass for the cluster to hold it together. The effect was confirmed in 1937 by the discovery of a similarly large velocity spread in the Virgo cluster by **Sinclair Smith**. Zwicky's paper was published in a German–Swiss journal, so he spoke of *dunkle materie* rather than dark matter, and suggested that it might consist of some combination of small, faint galaxies and diffuse gas (perhaps molecular hydrogen). Modern work has shown that both of these are present (though the gas is very hot and ionized rather than molecular), but that an even larger quantity of mass is some other form of dark matter. Zwicky's results implied that the average mass of a galaxy must be much larger than that advocated by Hubble, and he originally suggested that gravitational lensing of one galaxy by another would be a good way to decide which was right, and that it would also allow study of galaxies too distant and faint to be seen otherwise. These 1937 ideas both proved to be correct, but with the first such lens identified only in 1975 and mass measurements and Zwicky telescopes in the 1990s.

Zwicky did live to see the confirmation of another of his seminal ideas. Baade had come to Mount Wilson Observatory in the early 1930s. He was interested in novae, and Zwicky had begun to think that these stars might be sources of cosmic rays. Together in 1933/1934 they put forward the ideas that a small subset of novae were actually much brighter supernovae – **Knut Lundmark** had said the same thing a year or two earlier—that the energy source was the collapse of a normal star to a neutron star, that some of the energy would go into accelerating cosmic rays, and that the Crab Nebula was an example of the remnant of such an event and that one should look for a neutron star in it. Because the neutron had been discovered only in 1932, these were remarkably prescient ideas, which were confirmed by the discovery of pulsars in 1968 and a pulsar in the Crab Nebula in 1969. The Russian theoretical physicist **Lev Landau** also conceived the neutron star idea, probably independently, but somewhat later, and the first serious calculations were done by **Julius Robert Oppenheimer** and **George Volkoff** in 1939. Zwicky was never convinced that an object too massive to form a stable neutron star would collapse to a black hole (as implied by work by Oppenheimer and **Hartland Snyder** the same year), and advocated a hierarchy of more compact objects, beginning with pygmy stars and object Hades beyond neutron stars.

Zwicky had begun deliberate searches for supernovae using a small camera mounted atop Robinson Laboratory at Caltech in 1934, soon after his 1932 marriage to Dorothy Vernon Gates, daughter of a wealthy California family. The marriage ended in divorce, but not before Gates had paid a large fraction of the cost of the first telescope erected on Palomar Mountain, an 18-in. Schmidt in 1936, with which Zwicky began finding new supernovae for systematic study. Both supernova searches and a desire for a wide field of view to study clusters of galaxies motivated Zwicky to be a strong supporter of the 48-in. Schmidt, which began operation at Palomar in 1948. He personally discovered 122 supernovae (more than half of those known at the time of his death). Images from the Palomar Observatory Schmidt Survey also yielded a six-volume catalog of clusters of galaxies, completed by Zwicky and several collaborators in 1968 and still very much in use. He also compiled, in the wake of the 1963 discovery of quasars, a catalog of compact galaxies and compact parts of galaxies, and noted their connection with Seyfert galaxies. His catalog, with **Milton Humason**, of high-latitude B stars (HZ objects) turned out to include both a variety of highly evolved stars and some quasars.

During and after World War II, Zwicky worked on rocketry and propulsion systems with Aerojet (later Aerojet General) Corporation, for which he received a high civilian award, the United States Medal of Freedom in 1949. He was for many years vice president of the International Academy of Astronautics, and many of his more than 50 patents were in rocketry, although his 1957 attempt to put a small mass into cislunar space (with a secondary firing of a projectile off a rocket as it ascended) was probably a failure.

Zwicky was, in fact, a very hands-on scientist, who developed not only telescopes but ways of handling photographs, for instance the subtraction of a negative of one image from a positive of another (in another color, taken at a different time, or in a different polarization) to reveal aspects of galaxies and nebulae that would otherwise have been missed. Others of his ideas were extremely theoretical, for instance the possibility of estimating the mass of the particle that carries the gravitational force (the graviton) from the nonexistence of structures in the Universe larger than, perhaps, 100 megaparsecs on the distance scale then in use. The absence of larger structure turns out to be correct, the finite mass of the graviton probably not.

Zwicky had a number of nonastronomical interests, including Alpine climbing, the rebuilding of ravished European libraries after World War II, and the housing of war orphans, through the Pestalozzi Foundation, whose board of trustees he chaired for a number of years. Reminiscences of Zwicky (invariably attempting to reproduce his Swiss–German accent—he is said to have spoken seven languages, all badly) point out that, late in life, he became inclined to mention that he had been working on some astronomical problems for many decades, and quote one or more of his uncomplimentary remarks about colleagues, most often "spherical bastards" (meaning from which ever way you look at them). On the other hand, his claim that a particular Mount Wilson colleague was color blind in his description of stars turned out, upon application of the Ishihara test, to be literally true. This irascibility (though he could be very kind as well) is probably responsible for the paucity of honors Zwicky received, despite his enormous accomplishments. Apart from the Medal of Freedom, these were limited to the 1948 Halley Lecture (in which he presented the concept of morphological astronomy) and the 1972 Gold Medal of the Royal Astronomical Society.

Zwicky was survived by his second wife, Margrit Zurcher, whom he met and married in Switzerland, and their three daughters.

Oliver Knill

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